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ANALYSIS OF SMART CITY INITIATIVES TO SUPPORT ENVIRONMENTAL SUSTAINABILITY IN ASIA

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Abstrak

Studi ini bertujuan memberikan wawasan strategis untuk mengimplementasikan inisiatif kota pintar guna mendukung keberlanjutan lingkungan, sehingga pemerintah daerah di negara berkembang dapat mengelola kompleksitas kota pintar melalui teknologi Internet of Things (IoT). Fokusnya adalah beberapa kasus kota pintar di Asia, termasuk Jakarta (Indonesia), Da Nang (Vietnam), Tokyo (Jepang), dan Lusail (Qatar). Studi ini menggunakan wawancara mendalam dengan manajemen vendor IT dan konsultan bisnis yang terlibat dalam proyek kota pintar, serta tinjauan dokumentasi pemerintah. Hasilnya mengidentifikasi fase perencanaan, kemitraan, pemilihan teknologi, implementasi, serta evaluasi sebagai prioritas utama. Inisiatif kota pintar mengubah status quo area sasaran, sehingga keberhasilan implementasi membutuhkan kolaborasi pemerintah, penyedia teknologi, akademisi, dan warga. Pemerintah perlu menyesuaikan kerangka peraturan yang mencakup kepemilikan data, standar lingkungan, dan keamanan. Sektor swasta harus mengikuti perkembangan ini untuk memastikan kepatuhan sebelum memasuki pasar.

Kata kunci: Kota pintar; Keberlanjutan; *Internet of Things*

Abstract

This study aims to provide strategic insights into implementing smart city initiatives to support environmental sustainability, enabling local governments in developing countries to manage the complexity of smart cities through the Internet of Things (IoT) technology. The study focuses on several smart city cases in Asia, including Jakarta (Indonesia), Da Nang (Vietnam), Tokyo (Japan), and Lusail (Qatar). It utilizes in-depth interviews with IT vendor management and business consultants involved in smart city projects, along with a review of government documentation. Findings identify planning phases, partnerships, technology selection, implementation, and evaluation as key priorities. Smart city initiatives transform targeted areas or even entire cities, thus requiring collaboration among local governments, technology providers, academics, and citizens for successful implementation. Governments need to adjust regulatory frameworks, including data ownership, environmental standards, and security. The private sector should stay updated on regulatory developments to ensure compliance before market entry.

Keywords: Smart city; Sustainability; Internet of Things

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INTRODUCTION

Sustainability has been an active driver of smart city initiatives, with activities including implementing renewable energy sources, eco-friendly transportation, and effective management of resources. It refers to the focus on sustainable economic, social and environmental development at global and local levels (Rudewicz, 2023). Smart-city planners tend to build sustainable and resilient smart cities. Governments and cities have also established their policy frameworks on this approach. With the rapid acceleration of urbanization driven by a world population that is expected to reach 9.7 billion in 2050 and around 10.4 billion in 2080 (United Nations, 2022), it is seen that governments and the private sector are increasingly focusing on sustainability approaches and it is hoped that this will in turn result in more smart city use cases with sustainable practices. Examples of such practices include the implementation of smart grids, green city planning, smart transportation, and energy-efficient buildings, which will ultimately help address existing and potential environmental issues while improving the quality of life. However, it is believed that smart city planners should also invest in educating citizens about sustainability efforts, perhaps through campaigns or mobile applications, to amplify their impact. Countries and cities with strong economies and established technology adoption can more easily adopt smart city projects, while less developed countries and cities may face challenges such as financial constraints and limited technological infrastructure. Funding and financing are major challenges in implementing smart city projects, especially at a large scale. Therefore, it is expected that more and more private companies will be increasing their involvement in project financing. In addition, the feasibility, suitability, and adaptability of smart city implementation also depend on other factors such as local preferences and environmental conditions (climate, terrain, etc.). Furthermore, cities with limited knowledge of smart cities, which is common in developing countries, will face challenges such as the lack of clear regulations on smart city services and personal data protection; this lack of regulation has the potential to hinder the implementation of smart city projects. Finally, cities that collect and analyse large amounts of data need to establish regulations that ensure that data is stored and managed effectively.

Some sustainable development goals can be achieved through various techniques, including social solutions that can be supported by technology, but not necessarily created. As a result, there is a serious concern about whether the technologies associated with smart cities can contribute to sustainable development or even hinder or disrupt it as modern cities face challenges such as environmental pollution, climate change and population growth. Smart cities can be an answer to these challenges, but it is uncertain how smart cities can exactly contribute to sustainable development. Fortunately, various nations and organizations have a strong commitment to sustainability, driving the focus of management from pure energy to broader environmental parameters, such as water, air quality and waste (Gartner, 2022). Smart city application would be able to improve some key quality-of-life indicators including those related to sustainability by 10-30 percent (McKinsey&Company, 2018). Details are shown in Figure 1.

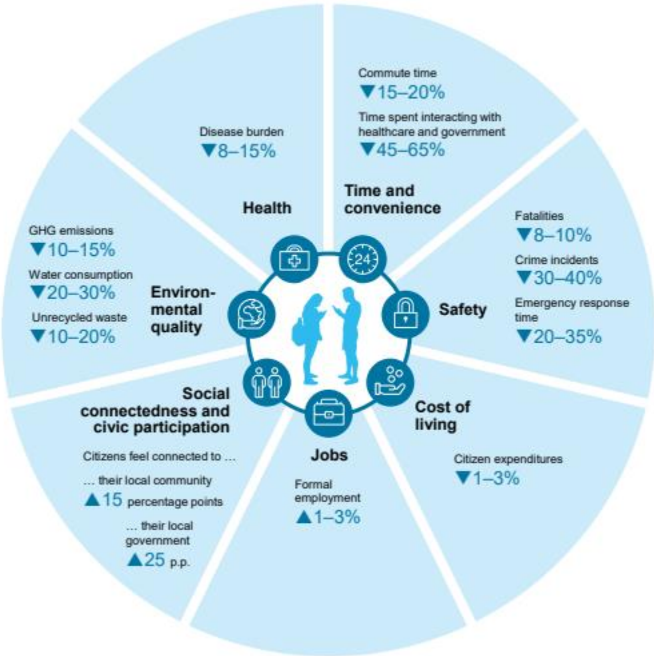


Figure 1. Potential Improvement Through Current Generation of Smart City Applications
Source: McKinsey Global Institute (2018)

The purpose of this study is to provide insights on some smart city initiatives focusing on sustainable development in Asia which can be applied by local governments as lessons learned from the success stories to overcome challenges across environmental sustainability. Due to funding and financing are still major challenges in implementing smart city projects in developing countries, especially at a large scale; public-private partnerships (PPPs) will remain the core model for implementing smart city projects, with governments, city agencies, technology providers, and domain experts pooling their talents and resources to develop innovative and sustainable smart city services and solutions. The practice of PPPs eases the funding demands on both public and private parties, provides access to city technology and infrastructure, and creates a more engaging way to engage with citizens.

LITERATURE REVIEW

The smart city concept integrates information and communication technologies (ICT), and various physical devices connected to the Internet of Things (IoT) network to optimize the efficiency of city operations and services and connect with citizens (Peris-Ortiz, Martha; Bennett, Dag R; Yábar, 2017), the objective of which is to improve living standards, enhance environmental sustainability, and benefit local businesses (Hope, 2022). Another quite similar definition, smart city is described as a smart urban ecosystem that leverages collected and processed data for citizen- and business-centric contexts (Tratz-Ryan, 2024). ICT is empowered to improve the quality, performance and interactivity of urban services, reduce costs and resource consumption, and enhance collaboration between citizens and government (NYC, 2015), while IoT is one of the core technologies, using devices, sensors, and infrastructure to interact with each other (Gillis, 2021); the SWOT analysis of IoT as the enabler for smart cities is described in Figure 1 (Eng, 2023).

Apart from the success stories of some smart city implementations to be discussed further in this paper, failures in smart city implementations cannot be ignored. In July 2024, it was reported that out of 100 cities selected for smart city projects in India, almost 50 percent of smart cities failed and have not implemented any projects under the public-private partnership (PPP) model (Joshi, 2024). The Standing Committee on Urban Development in India has observed several irregularities that lead to failure of smart city project implementation (ET Government, 2023). These irregularities include (i) frequent termination of projects after completing the proposal, (ii) repeating the same work again, and (iii) project costs higher than market rates.

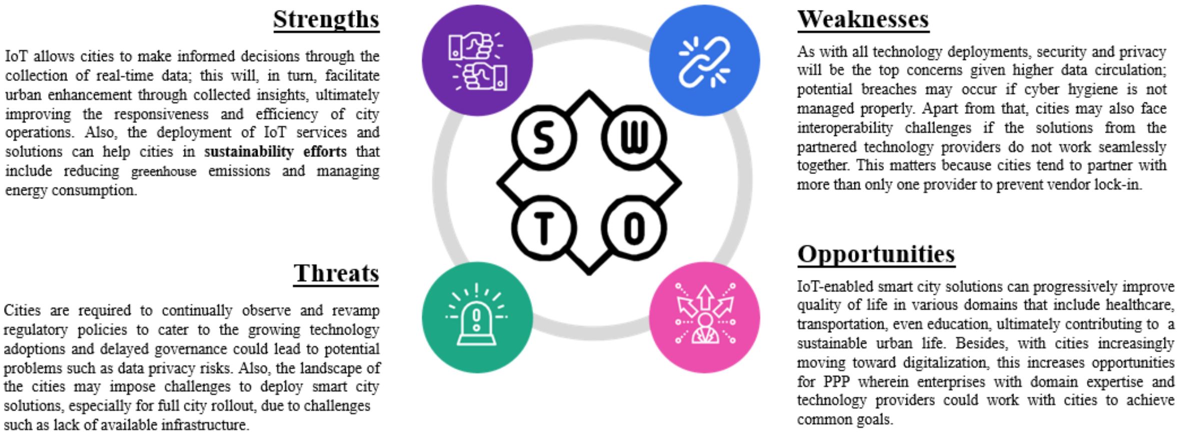


Figure 2. SWOT Analysis: IoT as an Enabler for Smart Cities

Source: Eng (2023)

In addition to the overview of general definitions, Toli and Murtagh reviewed a series of smart city definitions related to the idea of sustainable development and categorized these definitions, by determining the differences among academic (scientific) definitions, definitions formulated by the industrial environment, and institutional definitions that include the term “sustainability” (Toli & Murtagh, 2020). Meanwhile, the United Nations 2030 Agenda for Sustainable Development provides an ambitious and comprehensive plan of action, comprising 17 Sustainable Development Goals (SDGs), that serve as a blueprint for policymaking and international cooperation. The United Nations advances the 2030 Agenda in a “city-based approach” to sustainable development, with the aim of acknowledging the key and fundamental role that cities play in conveying, commencing, and governing sustainability (United Nations, 2020). As the superior form of structural organization of society, cities drive economic, social and environmental transformations. In other words, cities can be, and already are, power sources of these transformations towards greater sustainability.

Table 1. Smart City Definitions – Academic, Industrial, and Institution Definitions

Author	Keywords	Environmental	Economic	Social	Priority
SUSTAINABILITY ORIENTED DEFINITIONS					
Academic Definitions					
Bakici et al. (2010)	High-tech, connections, ICT, sustainable, greener city, competitive, innovative	•	•	•	Primary
Barrionuevo et al. (2012)	Technology, resources, integrated, habitable, sustainable			•	Secondary
Caragliu et al. (2011)	Human and social capital, ICT, Infrastructure, sustainable economic growth, quality of life, participatory governance	•	•	•	Primary
Lazaroiu and Roscia (2012)	Technology, interconnected, sustainable, comfortable, attractive and secure			•	Secondary
Giffinger and Pichler-Milanović (2007)	Economy, mobility, environment, people, living, governance	•	•	•	Primary
Kourtit and Nijkamp (2012)	Knowledge-intensive creative strategies, socio-economic, ecological, logistic competitive, human capital infrastructural, social and entrepreneurial capital	•	•	•	Primary
Kourtit et al. (2012)	Productivity, education, knowledge intensive jobs, creative, sustainability oriented			•	Tertiary
Nam and Pardo (2011)	Information, infrastructure, efficiency, mobility, decision making	•		•	Primary
Schaffers et al. (2012)	ICT, social and environmental capital, competitiveness	•		•	Secondary
Thuzar (2011)	Sustainable urban development policies, equity, sustainable economic development, human social capital, natural resources	•	•	•	Secondary
Toppeta (2010)	ICT, governance, sustainability, liveability			•	Primary
Zygiaris (2013)	Innovative socio-technical and socio-economic growth, green, interconnected, intelligent, knowledgeable, innovating, interactive	•	•	•	Secondary
Industrial Definitions					
Alcatel-Lucent (2012)	ICTs, competitiveness, environmental sustainability, liveability	•	•	•	Secondary
Bosch (2019)	Technology, quality of life, traffic, intelligent homes and energy efficient buildings	•		•	Tertiary
Hitachi (2012)	Environment, safe, quality of life	•		•	Primary
McKinsey (2018)	Digital intelligence, information, tools, services, businesses	•		•	Secondary
Microsoft (2018)	ICT, services, public utilities, safer and healthier city	•		•	Secondary
Aoun (2013)	Efficient, liveable, sustainable	•		•	Primary
Siemens (2017)	Resilience, social and human aspect, technology, services	•	•	•	Primary
Telefonica (2016)	Improving public services, quality of life, governance, sustainability			•	Tertiary
Institutional Definitions					
BIS (2013)	Liveable, resilient, engaging, hard infrastructure, social capital		•	•	Tertiary
BSI (2014)	Integrative, physical, digital and human systems, sustainable, inclusive			•	Secondary
EIP-SCC (2013)	Energy, materials, services and capital, sustainable economic development, resilience, quality of life	•	•	•	Primary
EIP-SCC (2013)	Technologies, environmental impact, better lives, governance	•		•	Primary
European Commission (2019)	Networks, services, ICT, resource use, emissions	•		•	Primary
Evergreen (2018)	Resilience, inclusivity, collaboration, data, quality of life			•	Primary
ICLEI (2017)	Operations, sustainable, resilient, physical and social capital	•	•	•	Primary
IDA (2006)	ICT, real-time analysis, sustainable economic development.		•		Primary
International Telecommunication Union (2016)	ICT, quality of life, city services, competitiveness	•	•	•	Primary
ISO 37122 (2019)	Collaboration, data, technology, quality of life, natural environment	•	•	•	Primary
NRDC (2012)	Efficient, sustainable, equitable, liveable	•		•	Primary

Source: Toli and Murtagh (2020)

RESEARCH METHODS

The data sources used to complete this study come from primary research (in-depth interviews) and literature reviews (i.e. documentation from local government public announcements, master plans, statistics, etc.). The primary data for this study comes from two stakeholders, namely the key management team of a particular international IT vendor that provides smart city implementation in certain countries in Asia along with a business consultant. This study focuses on exploring strategic smart city use cases in driving environmental sustainability in Asia, such as Indonesia, Vietnam, Japan, and Qatar. International IT vendors and consultants interviewed here included those who have extensive experience leading the implementation project of smart cities in Asia, from the design stage to the implementation stage supported by a research team with good reputation. Methodology used by the vendors and consultants in completing the smart city project involved global use case benchmark, discussions with local government to understand smart cities implementation pain points and needs in certain cities in Asia, followed by use case assessment, development, prioritization, partnership development with private vendors, and operating model definition.

RESULTS AND DISCUSSION

During in-depth interviews with international IT vendors and business consultants, the authors identify 5 key drivers of smart city implementation: First, rapid urbanization. The United Nations estimates that there will be 43 megacities by 2030, with an increase of 2.5 billion people living in cities and urban areas by 2050. Increasing population density has driven the need for smart city solutions to address challenges ranging from resource management to environmental sustainability. Second, modernization through technology. Cities are now looking to build on or upgrade existing infrastructure and address transportation, healthcare, and public services, with the addition of advanced features such as security monitoring, natural disaster notification, and environmental management. Third, sustainability focus. Sustainability has become an active driver of smart city initiatives, with activities including the adoption of renewable energy sources, environmentally friendly transportation, and effective resource management. Smart city planners tend to build smart cities that are sustainable and resilient. Governments and cities have also established their policy frameworks around this approach. Fourth, economic growth. Technology-enabled smart cities help stimulate economic growth and improve global competitiveness through several features, including attracting investment in smart cities, creating more job opportunities, and attracting external talent, as well as supporting tourism. Lastly, improving the quality of life. Smart cities can help improve the overall quality of life with improvements in education, healthcare, and transportation. In addition, smart city planners should consider citizen input to develop more effective local smart city solutions and use cases.

Those key drivers stimulated further explorations on use cases to overcome environmental sustainability, pollution, transportation and mobility, together with natural disaster concerns. The following sections will explore some smart city initiatives to drive environmental sustainability in Asia.

Smart City Use Case in Jakarta, Indonesia: Advanced Metering Infrastructure (AMI)

In June 2020, state-owned electricity company Perusahaan Asli Negara (PLN) announced plans to install 79 million smart meters nationwide by the end of 2027. As for Jakarta, the AMI pilot project was implemented in Cengkareng, West Jakarta, in 2018, with an expansion to South Jakarta in 2020. AMI is an urgent need in Jakarta and Indonesia because the region has suffered severe financial losses due to high transmission and distribution losses. There are approximately 14 million uncalibrated meters, resulting in inaccurate energy usage readings where power consumption has been overstated by

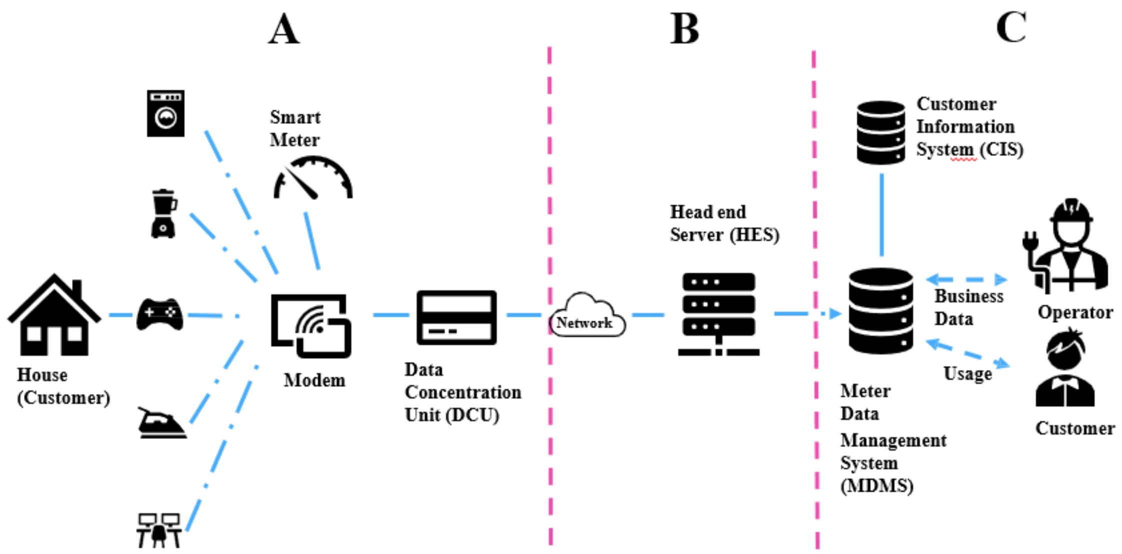
15% or underestimated by 17%. This situation was detrimental to both customers and electricity providers. PLN's 2018 report revealed that Indonesia had a very high average power outage duration per customer served, at 958.2 minutes, compared to Korea Electric Power Corporation (KEPCO) which only recorded 8.59 minutes.

Stakeholders for this pilot project included PLN as the utility provider as well as TIDE and KEPCO as the technology providers, with the aim of measuring the performance of communication technology for a two-way kWh meter system, which is a critical part of a smart grid system. In addition to testing the interoperability between meter data management systems (MDMS) and manufacturer meter reading devices, this second pilot project standardized specifications, software, design details, communication protocols, and standard procedures for testing and certification. Smart metering systems enable users to monitor their energy consumption in near real-time and coordinate communication between the demand and supply sides for an optimal and stable energy grid system.

The AMI pilot in Cengkareng was implemented using broadband power line communication (BPLC) which allows it to collect data from surrounding electronic meters more intelligently and in a pre-programmed manner. The system remotely collects information that includes measurement data, voltage, and current to help customers calculate their electricity bills. This allows customers to monitor power consumption and thereby reduce costs. The system can also check and detect power loss, theft, and other abnormal conditions in the metering system. Electricians use telemetry data to detect and handle these issues efficiently, thus avoiding unexpected disruptions or misuse of household electricity supply. Each public substation is equipped with a data concentrator unit (DCU) that enables data acquisition from smart meters, energy data transfer to a central database, and automatic electronic meter reading. In addition, a head-end server (HES) helps PLN monitor and evaluate the strength of the power line communication (PLC) network to detect meters with disconnected signals. Therefore, the server ensures efficient and accurate operation of the metering system. Meanwhile, the second AMI trial extended to South Jakarta completed the end-to-end AMI service testing, connecting smart meters to servers at PLN facilities.

As part of the trial, PLN also tested the relevant devices and software. These smart meters adopt international standards, i.e. the DLMS/COSEM protocol, which allows them to provide reliable functions according to international standards. A PLC modem is inserted into the smart meters and communicates with the DCU. The modem is stable and robust against noise interference. Each DCU is connected to approximately 400 smart meters. It also monitors information about the transformation of electricity distribution. On the other hand, the HES server collects measurement data and operates as a remote control for smart meters.

The Cengkareng pilot project recorded a success rate of 95.35%, while the second MDMS pilot project achieved a success rate of 96.94%. The results show that the PLC-based AMI system is a viable option for smart meter implementation in Jakarta. Figure 7 illustrates the AMI structure implemented during the pilot project.



A **Lower system** includes smart meter, communication modem and DCU.

B **Intermediate system** gathers metering data from lower system via the HES.

C **Upper system** analyzes metering data via the MDMS.

Figure 3. Jakarta's AMI Service Structure

Source: Author's Own Creation (2024)

However, there is a concern that residential smart meters are not fully suited to Indonesia's outdated electricity system. Due to the absence of a more advanced electricity grid on a large scale and unstable internet connectivity in most rural areas of the country, smart meters will not be able to optimally deliver the intended benefits.

Since 2020, PLN has planned to continue the pilot, or Proof of Concept (PoC) at several PLN facilities across the city that will involve other communication technologies, including radio frequency (RF) and cellular. So far there is no information indicating that Jakarta has trialled the use of an RF-based smart metering network.

AMI as part of the smart city implementation in Jakarta has had a tremendous impact. In addition to a significant reduction in Green House Gas (GHG) emissions in 2022, the level of customer satisfaction has also shown a fairly good increase, as evidenced by a sophisticated, accurate, and quality digital communication system, real-time monitoring of usage, early detection of disruptions so that they can be resolved immediately, better customer privacy protection, and a system that is integrated with other PLN services via PLN mobile.

Table 2. Sustainability Performance Highlights

Environmental Performance	Unit	2022	2021	2020
Total Green House Gas (GHG) Emission Reduction	Ton CO_2	6,043,479	2,160,249	Calculation of the results of GHG emission reduction initiatives has not been implemented
Social Performance	**Unit**	**2022**	**2021**	**2020**
Customer Satisfaction Survey	%	97.41	95.17	90.75

Source: *PT. PLN (Persero) 2022 Sustainability Report (2022)*

Smart City Use Case in Da Nang, Vietnam: Smart Electricity Meter

By the end of August 2019, 100% of electricity meters in the distribution network in Da Nang city had automatic and remote meter reading functions. Da Nang PC became one of the first electricity companies in the Electricity Vietnam (EVN) group to successfully switch from manual metering to automatic and digital metering. The modernization work is part of the smart grid development plan (2015–2020) and took more than five years to complete. Da Nang PC was scheduled to complete 100% automation of 22kV feeders by the end of 2022. The main stakeholder of this project was Da Nang Power One Member Limited Liability Company (Da Nang PC), with the purpose of monitoring the nation's energy consumption in real time and educating users about optimal energy use and simplify the process of resolving potential leaks.

Each public substation is equipped with a data concentrator unit (DCU) that allows data acquisition from smart meters, transfer of energy data to a central database, and automatic electronic meter reading. This smart metering system is implemented using a low-power RF network that allows it to collect data from surrounding RF electronic meters in a spider web pattern more intelligently and in a pre-programmed manner. The system remotely collects information that includes data on measurements, voltage, and current to help customers calculate their electricity bills. This allows customers to monitor power consumption and thereby reduce costs. The system can also check and detect power loss, theft, and other abnormal conditions in the metering system. Electricians use telemetry data to detect and handle these issues efficiently, thereby avoiding unexpected interruptions or misuse of household electricity supply. In addition, since 3Q19, customers can receive automatic alerts via email whenever their usage exceeds a set amount or increases by a pre-set percentage or level compared to the previous period. This feature allows customers to consume electricity efficiently and safely.

In addition, the head-end server (HES) helps Da Nang PC to monitor and evaluate the strength of RF waves and detect meters with disconnected signals. Therefore, the server ensures the efficient and accurate operation of the metering system 24/7 on the citywide electricity network.

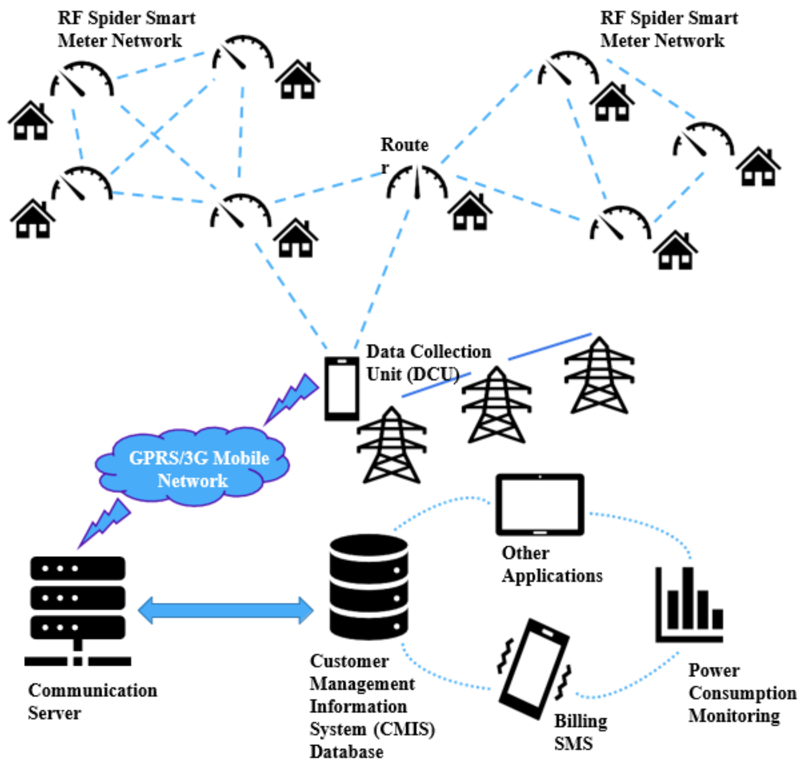


Figure 4. Illustration of A Smart Meter Pilot Project in Central Vietnam - Based on Radio Frequency (RF) Mesh Technology

Source: Author's Own Creation (2024)

On December 18, 2021, a member of Vietnam Electricity (EVN), the EVNCPC Da Nang's smart power supply solution received the Vietnam Smart City 2021 award in the field of smart energy solutions. The solution consists of three main components. First, real-time abnormal power output warning from telemetry**.** Da Nang PC's own software can analyse and warn abnormal power output in real time. The software accelerates short-circuit detection from 30 days to two to three days, and shortens the search period from 18% to 0.44% of total customers. Since its launch in 2020, the software has helped Da Nang PC detect more than 117 cases of power outages in the city. The tool has been deployed in the central region of the country and has enabled EVNCPC to detect more than 600 cases of short-circuits by December 2021. Second, distribution network automation system (DAS). In the event of a power grid failure, DAS will automatically analyse and identify the area where the failure occurred. The system will then isolate the affected area of the network by automatically emitting a signal to control the switching equipment in the network. DAS will then restore power supply. With the automation system, customers will only lose power for about 11–22 seconds during a grid failure. Otherwise, it would take 30–45 minutes. The system's fault location, isolation, and restoration of service (FLISR) greatly improves grid reliability. Third, power distribution system control centre for unmanned 110kV substation. This control centre provides Da Nang PC with full remote control over various aspects of the power system, including monitoring of operating status, fire alarm and security alerts, equipment control, and measurement data collection. The impact of implementing smart electricity meter use cases in Da Nang is demonstrated by the power loss rate in Vietnam Electricity (EVN) which shows a downward trend from 8.85% in 2012 to 6.24% in 2022 (Figure 5). This reduction in power loss was achieved through the implementation of various solutions including investment in network strengthening, optimization of operational methods to reduce technical losses and management solutions to reduce commercial losses, especially addressing electricity theft in the low-voltage distribution network.

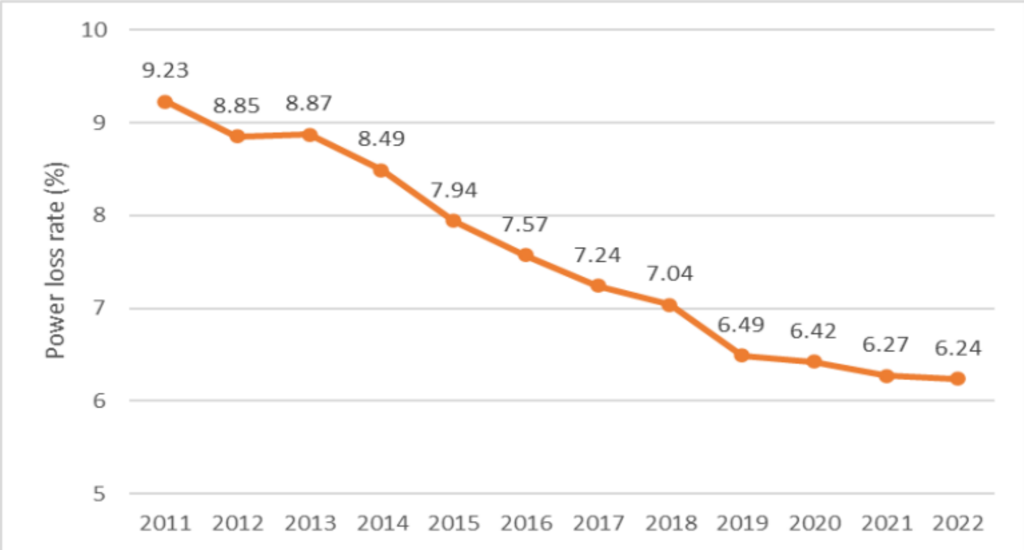


Figure 5. Reduction in EVN Power Loss Rates (2011-2022)
Source: Intelligent Energy Systems (2023)

Smart City Use Case in Tokyo, Japan: Toyota's Woven City

The Toyota's Woven City was announced in January 2020 - partial city launch on a 175-acre site at the base of Mount Fuji, about 63 miles from Tokyo. The construction was set to begin in early 2021, with first residents expected to move in within 5 years (Warren, 2021). Stakeholders involved Toyota, Nippon Telegraph and Telephone (NTT), Bjarke Ingels Group (BIG). The main aim of the project was to be a living laboratory for testing and developing technologies such as AI, robotics, personal mobility, autonomous vehicles, and smart homes; aims to create "a better way of life and mobility for all" (Toyota, 2020).

The real-world incubator will house 2,000 full-time residents and researchers. The city is envisioned as a place where people, buildings, and vehicles are all connected and communicate through big data and sensors. Residents will have human-assistive technologies at home such as robotics and sensor-based AI to help with daily life and basic needs. The city will also use sustainable energy, powered by solar power and hydrogen fuel cells that will be generated by rooftop photovoltaic panels. To minimize its carbon footprint, most of its buildings will be made of wood. The city will have open spaces throughout the city with hydroponics and native plants in addition to several parks and a large central plaza for social events (Wray, 2020). The city will have three types of streets, i.e. streets for a mix of low-speed vehicles and pedestrians, streets for faster vehicles only, and pedestrian-only routes such as parks. This organic grid pattern will help speed up testing of autonomy. Toyota's self-driving e-Palette electric vehicles will be used for deliveries, transportation, and "convertible mobile retail" throughout the city.

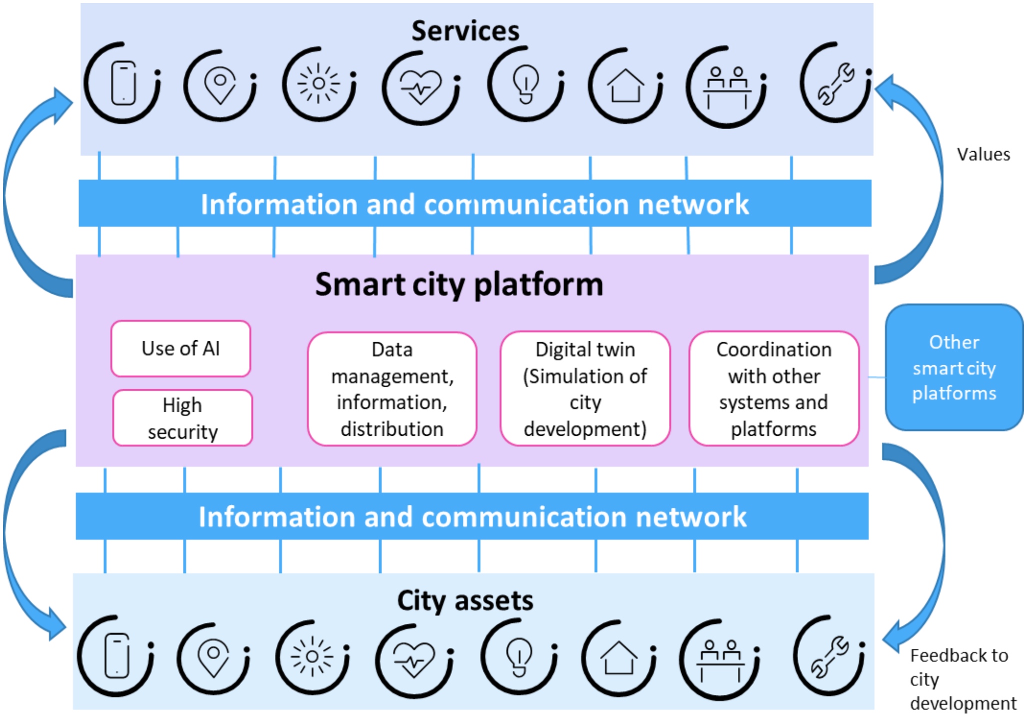


Figure 6. Illustration of Toyota's Woven City
Source: Toyota (2020)

Smart City Use Case in Lusail, Qatar: Free-Flowing SmartBall for Pipeline Monitoring and Mapping

In June 2014, Qatar General Electricity and Water Corporation ("Kahramaa") as the project owner awarded a three-year leak detection contract to US-based asset management and services company Pure Technologies for approximately $4 million. According to the contract, Pure Technologies would provide leak detection services through SmartBall on Kahramaa's large-diameter pipelines for desalinated water for residential, commercial and industrial use. The aim of this project was to detect leaks on Kahramaa's large-diameter pipelines, reduce wasted water (water lost before reaching customers) and prevent service disruptions.

The SmartBall is a battery-powered free-flowing device capable of inspecting pipelines with the help of several sensors (see below). The device is deployed into the pipelines and can operate for 16-18 hours per deployment. It has an aluminium-encased inner shell and a protective foam outer layer, which includes 7 key tools. First, an acoustic sensor that measures the changes in air pressure caused by the sound waves (acoustic signals) from all directions. It typically consists of a microphone that captures and processes sound waves as well as a transducer that converts them into electric signals. Second, a gyroscope that measures the device's rotation. It senses changes in the device's direction and reports the data. The device is helpful in validating Geographic Information System (GIS) data. Third, an accelerometer that measures the device's speed and directions. Both accelerometer and acoustic data allow precise identification of the leak location. Fourth, a magnetometer that detects the distance, speed, rotation, angle, and position of the device by responding to changes in the magnetic properties of the pipe wall and converting them into electrical signals. Fifth, a GPS receiver that receives signals from satellites for location and time information. Sixth, a memory card that stores collected data. It can be removed and transferred to a computer for data analysis. Seventh, SmartBall receivers, which is placed along the pipeline, pick up ultrasonic pulses from the device and record their passage time. This allows for an estimated location of the device.

In 2020, Kahramaa inaugurated a 269 km (167 miles) network of transmission pipelines of different diameters, a water reservoir, and a pumping station in Lusail City with a capacity of 6.6 million gallons per day. Kahramaa has inspected 307km (190 miles) of transmission pipelines with the SmartBall leak detection system, compared to 69km (43 miles) in 2019. In a "Delivering the right solutions to solve every water challenge" presentation by Xylem in 2020, the company stated that its SmartBall device has inspected over 1,220km (758 miles) of pipelines owned by Kahramaa in the country.

CONCLUSIONS AND RECOMMENDATIONS

There are four areas identified in this study to be considered as key prioritized items for implementing smart city initiatives to drive environmental sustainability. First, the planning stage, where city governments and local agencies need to assess and identify areas or domains that require process improvement (e.g., reducing traffic congestion or crime rates), usually through digitization. Once goals are agreed upon, these parties can begin working to establish policies and frameworks, and allocate funds to achieve those goals. Second, the partnership engagement and technology selection. After achieving an understanding and preparation to address the identified challenges, local governments and other city agencies begin engaging technology service providers and domain experts to determine and implement appropriate services and solutions. The number of partnerships depends on the scale of engagement and the desired outcomes. Third, the development and implementation. Selected partners will collaborate with project planners to develop concepts and frameworks for the solution and project implementation, then move on to a proof of concept (POC) phase to demonstrate the feasibility and reliability of the solution in the intended use case. Successful POCs will then be further revised and implemented in cities. Fourth, the assessment and evaluation. Both government/agency staff and technology partners involved will continuously assess the services and solutions implemented and use the data and feedback collected to improve the solutions. The information can also be used to develop more effective smart city frameworks and solutions.

As funding will always be a major issue in realizing smart cities in developing countries, public-private partnerships (PPPs), especially with foreign private companies that have mastered technological developments in technical cooperation and technological transfers, can play a key role in the smart city implementation. There are at least three aspects driving the growing PPP trend. First, access to technology and knowledge. Local governments and city agencies can tap into the wide range of technology offerings and expertise from the private sector to plan, develop and manage smart city projects; this is especially important when managing complex and large-scale projects. Second, reduced funding burden. Smart city projects, especially city-wide rollouts, are often expensive, and lengthy implementation processes can lead to budget constraints. Participation by both parties allows for shared funding, ultimately reducing such pressure and allowing efforts to develop any smart city solution and use case. Third, achieving targeted goals. Partners who are domain experts in areas such as security, environmental monitoring and disaster recovery have dedicated resources to help cities achieve their goals, which include sustainability and public safety.

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