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Smart Energy for Transportation and Health in a Smart City

Chun Sing Lai, Loi Lei Lai, Qi Hong Lai

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Chun Sing Lai
Guangdong University of Technology
China
Brunel University London
UK

Loi Lei Lai
Guangdong University of Technology
China

Qi Hong Lai
University of Oxford
UK

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Authors' Biography

Dr. Chun Sing Lai received the B.Eng. (First Class Hons.) in electrical and electronic engineering from Brunel University London, London, UK, in 2013, and the D.Phil. degree in engineering science from the University of Oxford, Oxford, UK, in 2019.

He is currently an Honorary Visiting Fellow of the School of Automation, Guangdong University of Technology, China, and a Lecturer in Circuits & Devices; he is also the Course Director, MSc Electric Vehicle Systems, with the Department of Electronic and Electrical Engineering, Brunel University London, UK. From 2018 to 2020, he was an UK Engineering and Physical Sciences Research Council Research Fellow with the School of Civil Engineering, University of Leeds, Leeds, UK. His current research interests are in power system optimization and data analytics.

Dr. Lai was the Publications Co-Chair for both 2020 and 2021 IEEE International Smart Cities Conferences. He is the Vice-Chair of the IEEE Smart Cities Publications Committee and Associate Editor for IET Energy Conversion and Economics. He is the Working Group Chair for IEEE P2814 Standard; Associate Vice President, Systems Science and Engineering of the IEEE Systems, Man, and Cybernetics Society (IEEE/SMCS); and Chair of the IEEE SMC Intelligent Power and Energy Systems Technical Committee. He received a Best Paper Award from the IEEE International Smart Cities Conference in October 2020. He was awarded the 2022 Meritorious Service Award by the IEEE/SMCS. Award citation is for meritorious and significant service to IEEE SMC Society technical activities and standards development. Dr. Lai has contributed to four journal articles that appeared in Web of Science as Highly Cited Papers, out of which he is the lead author for three of them. He is an IEEE Senior Member, an IET Member, and a Chartered Engineer.

Professor Loi Lei Lai received the B.Sc. (First Class Hons.), Ph.D., and D.Sc. degrees in electrical and electronic engineering from the University of Aston, Birmingham, UK, and City, University of London, London, UK, in 1980, 1984, and 2005, respectively.

Professor Lai is currently a University Distinguished Professor with Guangdong University of Technology, Guangzhou, China. He was a Pao Yue Kong Chair Professor with Zhejiang University, Hangzhou, China, and the Professor and Chair of Electrical Engineering with City, University of London. His current research areas are in smart cities and smart grid. Professor Lai was awarded an IEEE Third Millennium Medal, the IEEE Power and Energy Society (IEEE/PES) UKRI Power Chapter Outstanding Engineer Award in 2000, the IEEE/PES Energy Development and Power Generation Committee Prize Paper in 2006 and 2009, the IEEE/SMCS Outstanding Contribution Award in 2013 and 2014, and the Most Active Technical Committee Award in 2016.

Professor Lai is an Associate Editor of the IEEE Transactions on Systems, Man, and Cybernetics: Systems, Editor-in-Chief of the IEEE Smart Cities Newsletter, a member of the IEEE Smart Cities Steering Committee, and the Chair of the IEEE Systems, Man, and Cybernetics Society (IEEE/SMCS) Standards Committee. He is Conference General Chair of the 12th International Conference on Power and Energy Systems 2022 (ICPES 2022), IEEE. He was a member of the IEEE Smart Grid Steering Committee; the Director of Research and Development Center, State Grid Energy Research Institute, China; a Vice President for Membership and Student Activities with IEEE/SMCS; and a Fellow Committee Evaluator for the IEEE Industrial Electronics Society and IEEE/PES Lifetime Achievement Award Assessment Committee Member. He is an IEEE Life Fellow and IET Fellow.

Ms. Qi Hong Lai studied at Harrow International School Beijing, China, where she was awarded funding under the IEEE Systems, Man, and Cybernetics Society (IEEE/SMC) Pre-College Activities initiative to set up a program on Brain Computer Interface. She went on to gain her Bachelor of Science in Biomedical Science with First Class Honors from King's College London, UK, in 2019.

At present, she is working toward her Doctor of Philosophy in Molecular Cell Biology in Health and Disease at the Sir William Dunn School of Pathology, University of Oxford, UK.

She is the Working Group Secretary of the IEEE P3166 Standard on Smart Cities Terminology. Her current research interests are in transcription, bioinformatics, biotechnology, and smart health. She is an IEEE Student Member.

Foreword

As the world population continues to rise, the optimal management of major cities will play a key role in orchestrating the global responses to challenges posed by rapid urbanization. The notion of smart city is driven by stakeholders' intention to meet increasing societal demands as large city populations grow in all corners of the world. A prosperous smart city would manage a collection of large and critical infrastructures that support socioeconomic initiatives as it celebrates cultural and ethnic diversities. Smart cities manifest a safer, more secure, more economical, and more sustainable environment that promotes optimal resource allocation and utilization, industrial ecology, and energy conservation. However, a smart city is not all about decarbonization and energy sustainability. It also focuses on public safety, clean water utilization and conservation, public waste management, traffic control and congestion management, telemedicine and public health, and cyber-resilient communication for the automation of personal and social services that can improve the quality of life.

Smart cities rely on widely distributed smart devices to monitor and collect the pertinent data in real-time for intelligent decision-making. To accomplish the task, a distributed network of smart sensor nodes and data centers that stores and shares sensor data will make up the multiple levels of hierarchy in smart city infrastructures. Smart cities are operated in affordable and sustainable manners with more sophisticated control and management systems to ensure that social objectives can be attained in a fair and equitable style. The implementation of new technologies is also accelerated in smart cities as decision-makers and city planners seek to improve their effectiveness to manage limited resources in a more resilient fashion.

This book, which is on smart energy management for optimizing the transportation and healthcare infrastructures in a smart city, brings forth the importance of sustaining a secure, clean, and economical energy network in a smart city. In particular, the availability of a reliable, sustainable, and affordable supply of clean energy is critical for the electrification of smart city infrastructures. The respective authors provide a detailed coverage of these forthcoming topics and their roles in building smart cities.

The book is the product of major contributions of well-known experts and technical investigators with the goal of covering all levels of understanding to optimize the delivery of the concept to various interest levels. It explains in depth the compelling reasons for erecting smart cities and touches on analytical models that are deemed critical for analyzing the essence of establishing smart cities. Various practical examples and pertinent technologies are discussed to highlight the nucleus and promote the curtailed subject areas of energy, transportation, and healthcare in smart cities. The book provides various smart city stakeholders including operating managers, planners, practitioners, and research investigators with valuable insights on many levels of practical and academic landscapes as individuals embark on establishing smart cities for better serving their concerned citizens.

Mohammad Shahidehpour
Elected Member, US National Academy of Engineering
Life Fellow, IEEE
Fellow, American Association for the Advancement of Science
Fellow, National Academy of Inventors
University Distinguished Professor, Illinois Institute of Technology, Chicago, United States

Preface

To make city safer, more secure, and environmentally sustainable, environmental governance, public safety, city planning, industrial promotion, resource utilization, energy conservation, traffic control, telemedicine, interpersonal communication, education, social activities, and entertainment are focused upon. Smart cities have been driven by the desire of citizens to meet increasing demands and allow the choice on the basis of price and service provided. The dramatic changes in the organization of city management bring new challenges and opportunities, by a new competitive and marketable framework. This book was written in response to the growing interest in green smart city technology and its deployment on a global scale. People firmly believe that the technology will produce win-win solutions in terms of environmental, social, and economic impacts.

To achieve net-zero emissions by 2050, preserve biodiversity, and mitigate global warming, people are committing to building a better and more sustainable world. Smart energy will play a key role in a carbon-neutral society. Major environmental, economic, and technological challenges such as climate change, economic restructuring, pressure on public finances, digitalization of the retail and entertainment industries, and growth of urban and ageing populations have generated huge interest for cities to be run differently and smartly.

Smart health will enable medical practitioners to manage patient health using digital means in a secure and private environment whenever and wherever care is required. Road traffic accidents are one of the major causes of injury-related deaths. Safety is the highest priority for transportation. The application of the Internet of Things (IoT) is of special interest to support the aim of efficiently transforming cities to acquire more substantial and sustainable development, as well as a higher quality of life by using data for decision-making to control resources and assets more efficiently.

Smart city is now a hot topic, but its definition and specifics remain unclear. This has led to different interpretations of a smart city. A smart city may be described by six basic pillars: (i) smart economy that improves competitiveness, (ii) smart people relating to social and human capital, (iii) smart governance handling social operation decisions, (iv) smart mobility integrating ICT with transportation to minimize fatality and maximize comfortability, (v) smart environment aiming to achieve net-zero emission through the utilization of natural resources, and (vi) smart living seeking to improve quality of life and life expectancy.

This book focuses on delivering a comprehensive and detailed analysis of smart energy, smart transportation, smart infrastructures, and smart health. The purpose is to first inform readers through a more general but comprehensive coverage of the smart city concept, and then go deep into more specific areas, rather than over-specialization, as to avoid only presenting qualitative data and numerical techniques, and where feasible, provide actual case studies and project discussions.

The book is composed of five parts, namely, Part 1 is the Introduction as presented in Chapter 1; Part 2 is related to smart energy for smart cities and is presented in Chapters 2–11 on power systems, battery, PVs economy and cost, planning, demand response, network microgrids, home energy management, virtual energy storage, reliability modeling of CPS, and vehicle-to-grid; Part 3 is related to smart transportation to related to fast-charging station, electric vehicles, and parking vehicles based on machine learning and wireless communication and is presented in Chapters 12–16; Part 4 is related to smart health and is presented in Chapters 17–19; and Part 5 is the concluding remarks and proposed future directions for smart cities and this is given in Chapter 20. The details for each chapter are given as follows.

The first chapter discusses the definition of a smart city and explains its functions, characteristics, and domains. It will go through some case studies and the established standards of smart cities worldwide.

Chapter 2 introduces a state-of-the-art financial model that has achieved novel and meaningful financial and economic results when applied to lithium-ion (Li-ion) electrical energy storage (EES). Real solar irradiance and load and retail electricity price data from Kenya were used to develop a set of case studies. EES is combined with photovoltaic and anaerobic digestion biogas power plants.

Due to the diurnal and intermittent nature of solar irradiance, photovoltaic (PV) power plants will introduce power generation and load power imbalance issues. Anaerobic digestion (AD) biogas power plants also have a partial load operation constraint that needs to be met. To overcome these limitations, EES is needed to provide power generation flexibility. Chapter 3 reports on the optimal operating mechanism designed for the PV-AD-EES hybrid system, followed by the study of the levelized cost of electricity (LCOE). The degradation cost per kilowatt-hour and the degradation cost per cycle of EES are considered. The study used the 22 years (1994–2015) irradiance data of Kenya's Tkwell Canyon Dam (1.90 °N, 35.34 °E) and Kenya's national load.

With demand-side management (DSM), several electricity prices have emerged, and residential customers are faced with the challenge of choosing a plan that meets their individual needs. The Electricity Plan Recommender System (EPRS) can alleviate this problem. Chapter 4 proposes a new EPRS model integrated with electrical instruction-based recovery (EPRS-EI) to restore electrical appliance usage and set the recovered data as features that represent the customer's life pattern. With these functions, a personal electricity plan is recommended.

Chapter 5 proposes a new classifier network construction method: non-intrusive load monitoring (NILM) and semi-intrusive load monitoring (SILM). This method is not to create a classifier for NILM or SILM but to help decision-makers choose different types of classifiers and optimize the location of the classifiers. In this method, the economy of each classifier is considered to ensure that the cost of decision-makers is reduced. A combinatorial optimization problem is established on the tree-type model for the optimized classifier network. Numerical studies on public data sets and industrial operation data have demonstrated the benefits obtained.

Demand response (DR) is one of the typical methods to optimize the load characteristics of the power system. Chapter 6 introduces the boundary model framework for the construction and transformation of consumer behavior of household appliances. Electricity tariffs are analyzed by this model for their load variation potentials.

Case studies are also included to reflect the implementation potential of the model framework in terms of pricing and smart meter deployment.

Chapter 7 proposes a novel two-stage game-theoretic residential PV panels planning framework for distribution grids with potential PV prosumers. A residential PV panels location-allocation model is integrated with the energy sharing mechanism to increase economic benefits to PV prosumers and meanwhile facilitate the reasonable installation of residential PV panels. Simulations on IEEE 33-node and 123-node test systems prove the effectiveness of the proposed method.

Chapter 8 proposes a two-stage energy management strategy for networked microgrids in the presence of a large number of renewable resources. It decomposes the microgrids energy management into two stages to offset the intra-day stochastic variations of renewable energy resources, electricity load, and electricity prices. According to the simulation results, the proposed method can identify optimal scheduling results, reduce operation costs of risk-aversion, and mitigate the impact of uncertainties.

Chapter 9 proposes a novel framework for home energy management (HEM) based on reinforcement learning in achieving efficient household DR. The Extreme Learning Machine (ELM) processes real data on electricity prices and solar PV power generation promptly in a rolling time window to make uncertain predictions. The simulation was performed at the residential level, which included multiple household appliances, an electric car, and multiple PV panels. The test results prove the effectiveness of the proposed data-driven HEM.

Chapter 10 proposes a two-level consensus-driven distributed control strategy to coordinate virtual energy storage systems (VESSs), i.e. residential households with air conditioners, to avoid the violation of voltage and loading, which are regarded as part of the main power quality issues in future distribution networks. Changes in dynamic communication network topology are studied to prove their impacts on system performance. Simulation results based on an actual system in NSW, Australia, are used to demonstrate the proposed control scheme that can effectively manage voltage and loading and is scalable and robust.

Chapter 11 proposes a reliability modeling and evaluation method for the power information system, i.e. cyberspace in power system. The proposed composite Markov model will couple physical characteristics and information flow performances in a two-layer model. The proposed reliability method combines sequential Monte Carlo simulation with a linear programming model to obtain the maximum flow that can meet the power demand.

Chapter 12 introduces the co-simulation integration of the direct-execution simulator, which provides special support for distributed smart grid software. A case study of agent-based smart grid restoration using this new type of co-simulation platform is conducted. The results show that the proposed direct-execution simulation framework can promote the understanding, evaluation, and debugging of distributed smart grid software. A case study on vehicle-to-grid voltage support application is given.

Chapter 13 reports on the development of Advanced Metering Infrastructure (AMI), which is an effective tool to reshape the electric vehicle (EV) charging load curve by adopting appropriate DSM strategies. An overall solution for an electric vehicle charging service platform (EVAMI) based on power line and Internet communication is proposed. EV owners understand their energy usage, so they can effectively carry out energy-saving activities.

Since plug-in hybrid electric vehicles (PHEVs) are expected to be widely used in the near future, in Chapter 14 a mathematical model is developed based on the traditional security-constrained unit commitment (SCUC) formulation to address the power system dispatching problem with PHEVs taken into account. A real system in China is used to study the impact of PHEV charging on the distribution system. It is proved that charging brings peak load to the grid, and control is essential to reduce the risk of instability.

As more and more electric buses (EBs) are put into use, the reasonable location of charging stations plays an important role in the process of bus electrification. Chapter 15 proposes a location planning model for EB fast-charging stations that considers the bus operation network and the distribution network. The goal of the model is to minimize the sum of the construction cost of charging stations, the operation and maintenance costs, the cost to go to charging stations, and the distribution network losses. The model is applied to simulate and analyze the bus public transportation of a coastal city in South China. The case study shows that the model can effectively optimize the layout of a city's bus charging stations.

Infrastructure and applications based on the IoT are essential for smart cities deployment. The low power wide area network (LPWAN) plays a key role in IoT techniques due to its wide coverage and low power consumption. However, it is hard to decide which one of the LPWAN techniques to be implemented in a specific application to obtain best practice. Therefore in Chapter 16, the main characteristics of the three popular LPWAN technologies, namely, LoRaWAN, NB-IoT, and Sigfox are discussed, and LP-INDEX is proposed to weigh performance factors according to application requirements. To further distinguish the differences, a comparative test based on parking detection sensors using the three different technologies was carried out as a case study.

It is foreseen that the trends for the next decade in healthcare will include more patients requiring care, increased use of technology, the need for greater information storage capacity, development of new healthcare delivery models, error reduction, more emphasis on preventative healthcare, and faster disease diagnosis and innovation-driven by competition. It is important not only to improve patient care processes but also to decrease costs while maintaining quality. Chapter 17 reviews the benefits and challenges of innovations in healthcare, with emphasis on the IoT and smart devices. In Chapter 18, an electrocardiogram (ECG) scheme based on multiple criteria decision-making approach and analytic hierarchy process is proposed to detect drunk status for drivers. Chapter 19 explains the use of bioinformatics and telemedicine for healthcare. Some models, designs, and frameworks for potential applications will be illustrated.

In addition to the smart energy, transportation, and health mentioned in the first19 chapters, there are more elements in a green smart city, such as water and waste; biology, food, and agriculture; education, safety and well-being; government engagement with society and citizens; social entrepreneurship, digital finance, and legal and economic development; sustainable flexible buildings and infrastructure; and open data, privacy, and security for research. In the final Chapter 20, the authors formulate the roadmap and the interrelationships between certain elements. Based on current work and existing information, some suggestions are made, and an overall view of the development and deployment of green smart cities in the next ten years or so has been put forward, and the progress of smart energy, health, transportation, and construction has also been critically evaluated.

This book addresses the latest problems and solutions of smart cities in a coherent manner. It is the product of the contributions of world-class experts, educators, and students, so it covers all levels of understanding to optimize its delivery. Therefore, we believe it will provide decision-makers, engineers, doctors, educators, system operators, managers, planners, practitioners, and researchers with valuable insights on all levels of professional and academic progress.

Chun Sing Lai
Loi Lei Lai
Qi Hong Lai
From Guangzhou, China, and London and Oxford, UK

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1

What Is Smart City?

1.1 Introduction

One of the reasons behind the lack of unified definitions of a smart city is because of the various entities involved and the functions the smart city provides. Hence, existing definitions can vary greatly. There are several definitions for a smart city which are defined by various organizations and stakeholders.

The most common consensus is that the smart city employs various kinds of digital and electronic technologies to transform the living environments with Information and Communications Technologies (ICTs) [1, 2]. Deakin [3] labeled the smart city as a city that employs ICT to meet the market (the citizens') needs. There is a need for larger community involvement to achieve a smart city. A smart city does not simply contain ICT technology but has also developed the technology to achieve positive impacts to the local community. Some definitions for a smart city from major professional organizations and government agencies are given as follows:

Association of Southeast Asian Nations [4]: "A smart city in ASEAN harnesses technological and digital solutions as well as innovative non-technological means to address urban challenges, continuously improving people's lives and creating new opportunities. A smart city is also equivalent to a 'smart sustainable city,' promoting economic and social development alongside environmental protection through effective mechanisms to meet the current and future challenges of its people, while leaving no one behind. As a city's nature remains an important foundation of its economic development and competitive advantage, smart city development should also be designed in accordance with its natural characteristics and potentials."

British Standard Institution [5]: A smart city is an "effective integration of physical, digital, and human systems in the built environment to deliver a sustainable, prosperous, and inclusive future for its citizens."

Department for Business, Innovation, and Skills, UK [6]: "A Smart City should enable every citizen to engage with all the services on offer, public as well as private, in a way best suited to his or her needs. It brings together hard infrastructure, social capital including local skills and community institutions, and (digital) technologies to fuel sustainable economic development and provide an attractive environment for all."

European Commission [7]: "A smart city is a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business. A smart city goes beyond the use of ICT for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal

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facilities and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population."

Innovation and Technology Bureau, Hong Kong [8]: "Embrace innovation and technology to build a world-famed Smart Hong Kong characterized by a strong economy and high quality of living."

Institute of Electrical and Electronics Engineers Smart Cities Community [9]: A smart city gathers government, technology, and society to achieve a minimum of the following factors: smart mobility, a smart economy, a smart environment, smart cities, smart governance, smart people, and smart living.

International Electrotechnical Commission [10]: "A smart city is one where the individual city systems are managed in a more integrated and coherent way, through the use of new technologies and specifically through the increasing availability of data and the way that this can provide solid evidence for good decision making."

Japan Smart Community Alliance [11]: The expression "Smart Community" is more widespread than "Smart City" in Japan [7]. "A smart community is a community where various next-generation technologies and advanced social systems are effectively integrated and utilized, including the efficient use of energy, utilization of heat and unused energy sources, improvement of local transportation systems and transformation of the everyday lives of citizens."

Ministry of Housing and Urban Affairs, India [12]: "The conceptualization of Smart City, therefore, varies from city to city and country to country, depending on the level of development, willingness to change and reform, resources and aspirations of the city residents. A smart city would have a different connotation in India than, say, Europe. Even in India, there is no one way of defining a smart city."

According to the above, the similarity and differences in smart city definitions can be summarized as follows:

- Similarities:
  - Enhancement of living standards by making informed decisions with advanced technologies to collect, process, and evaluate data.
  - Systems are integrated to exchange information.
  - Citizens are better informed about their surroundings.
  - Sustainability and environmental conservation should be maximized.
- Differences:
  - Smart city domains or elements, e.g. transport, energy, and health (explained in the following section), can be different due to regional interests.

From the above summary, it is shown that for a city to become smart, multiple sources of data from a range of urban activities and domains must be connected to reveal opportunities to bring innovation to today's connected citizens. Deloitte [13] stated that a smart city is driven by the innovation success of six key domains including:

1) Energy and environment: sustainable growth is created by technology and cities make better use of resources from electronic sensors that monitor leakages, as well as gamification and behavioral economics to support citizens to conduct considerate decisions on resource utilization [14]. Renewable energy including solar and wind will be important sources of energy generation [15–17]. Data analytics will be used to enhance energy and power system operation [18].

2) Economy: the economy will be affected by digitization and disruptive technologies, which will change the needs of several types of jobs. Smart cities need to create strategies to adopt future jobs that will power Industry 4.0 and beyond [19].
3) Safety and security: as criminals will make use of technology to commit advanced crimes, public safety and security authorities will also use technology for crime prevention by assessing multiple streams of social and crowdsourced information, including super-resolution images [20] and image fusion [21].
4) Health and living: the lives of citizens are enhanced with technology and connectivity. Connected communities are achieved with smart buildings. Enhanced social programs and innovated health care sector are data-driven [22].
5) Mobility: the integrated mobility systems include autonomous vehicles and shared mobility services achieved with the Internet of Things (IoT). The concept of IoT occurs when devices are communicating with other devices on behalf of people and will dominate the future of Internet communications [23]. Advanced analytics allow citizens and goods to travel in ways that are safer, cheaper, cleaner, and faster [24].
6) Education and government: technological advancement will aid government procedures and give a seamless experience to businesses. Smart cities use analytics to assist authorities to create insight-driven policies, monitor performance and outcomes, allow constituent engagement, and enhance government efficiency. Data and analytics will also assist next-generation teachers to familiarize their counseling and teaching for greater student achievement. More creative and personalized education plans can be created such as virtual learning environments [25].

Similarly, Giffinger et al. [26] described the smart city as having six domains, including:

1) Smart economy: consists of features surrounding economic competitiveness including entrepreneurship, innovation, flexibility, the productivity of the labor market, trademarks, and participation in the global market.
2) Smart people: concerns not only the level of qualification or education received by citizens but also additional social interactions and perceptions of public life.
3) Smart governance: concerns political involvement, citizen services, and administration functions.
4) Smart mobility: includes local and global accessibility with the presence of ICTs and sustainable and relevant transport systems.
5) Smart environment: concerns attractive natural conditions including green space, less extreme climate, reduced pollution, resource management, and working to achieve environmental protections.
6) Smart living: includes many features of quality of life composed of health, housing, culture, tourism, and safety.

It is worth noting that there are other domains apart from smart energy, smart transportation and smart health (to be discussed further later), including:

Smart water [27, 28]: Smart water systems employ IoT-enabled sensors to collate real-time data. With precise and reliable data, smart water systems can drive great transformations in water sector transparency and accountability. There will be governance improvements, risk reductions, water quality control, and eventually novel business cases for water sector investment [28]. The data allows water facilities optimization by detecting leaks or observing how water is distributed in the water network. The optimization model empowers citizens to make better decisions about water management. Smart sensors can detect water pipe leaks and quickly inform engineers to take action and resolve the issue. Smart water is critical as an estimated 3.3 billion liters of water is wasted daily in Wales and England due to leaks in water networks [27].

Smart waste [29, 30]: Interreg Europe [30] described smart waste as being used "to improve public policy instruments supporting innovation within waste management procedures. The final result? Smarter, more effective, sustainable, and cost-efficient waste management, benefiting all territorial stakeholders." In the United Kingdom, illegal waste activity including fly-tipping costs the UK economy approximately £600 M annually [29]. The present systems for monitoring commercial and household waste are out-of-date and mainly paper based. Smart waste employs technology including blockchain [31], electronic chips, and sensors for monitoring waste, waste containers, and waste vehicles. Smart waste is an element of smart living and smart environments.

In summary, a smart city is an ambitious and crucial transformation of many cities worldwide. Benefits including improved living conditions are reaped from several sectors/domains. However, a smart city consists of the development and application of novel technologies. There is a need for standardized uniform engineering or technical criteria, methods, processes, and practices. The next section examines how international standards help to build a smart city.

1.2 Characteristics, Functions, and Applications

1.2.1 Sensors and Intelligent Electronic Devices

A sensor is a device aiming to detect events or changes in its environment and send the information to other electronic modules. It responds to a stimulus, such as heat, light, or pressure, and generates a signal that can be measured.

A good sensor must have the features sensitive to the measured property, but insensitive to any other property likely to be encountered in its application, and it will not influence the measured property.

Sensors are used in everyday objects such as touch-sensitive lamps which dim or brighten by touching. With the advancement in industry, the use of sensors has expanded beyond temperature, pressure, or flow measurement. Applications include vehicles, manufacturing, machinery, airplanes, medicine, and many other areas of our day-to-day life. There are a wide range of other sensors, measuring chemical and physical properties of materials. Some examples consist of optical sensors for refractive index measurement, vibrational sensors for fluid viscosity measurement and electro-chemical sensor for monitoring pH of fluids.

A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes. For instance, if the mercury in a thermometer moves 1 cm when the temperature changes by 1 °C, the sensitivity is 1 cm/°C by assuming there is a linear relationship. Some sensors can also be affected what they measure, namely, a room temperature thermometer inserted into a hot cup of liquid cools the liquid while the liquid heats the thermometer. Sensors are usually designed to have a small effect on what is measured; therefore by making the sensor smaller can often improve accuracy and introduce other advantages, for example, convenience in installation.

Technological progress allows more and more sensors to be manufactured such as microsensors which can have a significantly faster measurement time and higher sensitivity compared with macroscopic approaches. Due to the increasing demand for rapid, affordable, and reliable information, low-cost and easy-to-use devices for short-term monitoring or single-shot measurements have gained growing importance. Using this class of disposal sensors, critical analytical information