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Japan's Experience of Creating Innovation for Smart Cities: Implications for Public Policy for Urban Sustainability

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Abstract

In our efforts to promote an urban sustainability, the transformation to smart cities will play a significant role. As smart cities are based on advanced systems of hardware and software—covering various types of products and services relevant to urban functions—innovation for smart cities requires a significant degree of diversity in knowledge, actors, and institutions. Hence it is important to understand the characteristics of the innovation system in smart cities and to introduce policies that will promote forms of innovation that incorporate local conditions and contexts. In this paper, the innovation system of smart cities in Japan is examined to consider implications for public policies and institutional design. The analysis reveals a concentrated structure dominated by large actors, particularly in the public sector and the electric (power generation and distribution) and electronics (appliance and equipment) industries, with knowledge and technological domains concerning renewable energy, energy storage, community energy management, and applications for home appliances and electric vehicles. Policies and regulations influencing the innovation system of smart cities include economic incentives to promote renewable energy technologies, liberalization of energy markets for new entrants, participatory processes of road-mapping on key technologies, localization of demonstration projects reflecting specificities, standard setting for component technologies, and platform creation for stakeholder partnerships including academia, industry, government, and civil society. A key implication for public policy is to facilitate communication and engagement with end users in jointly creating innovation for smart cities.

Keywords: smart city, innovation system, network analysis, stakeholder collaboration, Japan

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This paper is part of a number of country cases within the JICA Research Institute's research project, "A Study on Urban Air Pollution Improvement in Asia," which focuses on PM2.5 and other air pollution problems and analyzes relevant policies, primarily in Asian countries.

1. Introduction

The eleventh goal of the Sustainable Development Goals (SDGs) is aimed at developing cities that are inclusive, safe, resilient and sustainable (United Nations 2015). This paper is part of a number of country cases within the JICA Research Institute research project, “A Study on Urban Air Quality Improvement in Asia,” which focuses on PM2.5 and other air pollution problems and analyzes relevant policies—primarily in Asian countries. In our efforts to achieve urban sustainability, smart cities are expected to play a critical role (Bibri and Krogstie 2017). Currently, many urban functions, including energy, transportation, and buildings, are currently undergoing a significant transformation following the advent of smart devices and equipment (Curley 2016). In the power sector, for example, a smart grid system can lower costs, integrate renewable energies, and balance loads, which contributes to improving energy efficiency and reducing carbon dioxide (CO_2) emissions. In the transportation sector, a dynamic congestion-charging system can adjust traffic flow and offer incentives to use park-and-ride schemes, depending upon real-time traffic levels and air quality, whereas car-to-car communication can manage traffic to minimize transit times and emissions and eliminate road deaths from collisions. These emerging innovations based on smart technologies are increasingly connecting various urban functions to create smart cities.

In smart cities, a particularly important role is played by smart grids, which can be understood as an electricity network that can intelligently integrate the actions of all users connected to it—including both generators and consumers—in order to efficiently deliver sustainable, economic and secure electricity supplies (European Technology Platform for Electricity Networks for the Future 2016). By bundling various types of equipment and practices, along with the introduction of new functionalities, smart grids constitute an aggregate system to improve electricity generation, distribution, and consumption. Based on smart grids, smart cities have been developing sophisticated systems of hardware and software that are capable of processing an increasing amount of information on the multifaceted aspects of cities. This contributes to the production of various types of products and services.

The idea of smart cities, therefore, reflects different dimensions of complex technological assemblages and, as such, there are significant differences in the nuances and emphases within the concept. These depend upon the specific contexts and conditions. In Europe, the focus is on creating an infrastructure that can use information collected and distributed among all connected users to ensure that the various objectives of the electricity grid are achieved in more intelligent ways (Clastres 2011). In the United States, there is a specific emphasis on security, involving key features such as self-healing and resilience against physical and cyber threats. Because there are numerous functionalities discussed as part of the smart city, there are also a wide range of benefits envisioned for societies when smart cities are implemented. Potential benefits include higher overall energy efficiency, lower costs of operating the electricity grid, lower environmental impacts, higher resilience of the energy system and greater empowerment of end-users in the energy system.

Given the potential benefits for societies that are facing the effects of air pollution and climate change and the high hurdles faced by such complex systemic technology areas, public policies are crucial in facilitating innovation for smart cities. With a variety of hardware as well as software for smart cities, the technologies, stakeholders, and institutions involved are diverse and influenced by economic, social, and environmental conditions. An in-depth examination of the processes of creating innovation will generate valuable lessons for public policies and institutional design. Utilizing the experiences of industrialized countries to generate policy and institutional implications will be particularly important for many countries in the developing world, where urbanization is proceeding rapidly in many major cities. This is generating difficult challenges in pursuing sustainability. Within the relatively short period of time in which smart cities have evolved, there have not been many studies with macroscopic views on innovation for smart cities, particularly those studies conducted from policy perspectives (Lin, Yang, and Shyua 2013).

In this paper, a systemic approach is used to examine the processes of creating innovation for smart cities through the case study of Japan. As there have not been any previous attempts to apply the systems of innovation (Soete, Verspagen, and Weel 2010) approach to analyzing the mechanisms of creating innovation in smart cities, it is hoped that the discussion in this paper will produce some useful findings with implications for public policy and institutional design.

The analysis examines the kinds of actors that are involved, the areas of knowledge and technological expertise, and the effects and impacts that have resulted from policy interventions. Based on project documents used in the advancement of smart cities, network analysis isutilized to identify key stakeholders involved in innovation for smart cities and to analyze the relationships between them. This illustrates how important organizations are located and how they interact in the communities of smart cities. The functions in the innovation system of smart cities are also examined to understand the process of developing and introducing smart cities. Based on this analysis of the experiences of Japan, the conclusion considers the lessons and implications for public policy as well as institutional design for promoting urban sustainability.

2. Innovation Systems Approach

One of the major analytical approaches to studying innovation processes is the framework of innovation systems. It is based upon the notion that the character of technological change is determined not only by the activities of researchers and companies but also by the broader societal and institutional structures. The idea of the system of innovation was originally developed to examine the functioning of national systems of innovation, particularly how the key actors in the system could actively promote innovation through interactions and networking in the national context (Freeman, 1988; Lundvall, 1988; Nelson, 1993).

To understand the characteristics of innovation in a particular sector, it is useful to identify a sectoral innovation system. A sectoral innovation system is understood to consist of three main dimensions: knowledge, actors, and institutions (Malerba 2002, 2004). The knowledge dimension deals with the specificities of knowledge and technological aspects that are relevant to the innovation. The actors involved in the innovation system show heterogeneity, networks, and interactions between them. Institutions include formal ones such as policies, regulations, and standards as well as informal ones like norms, customs, and established practices. Within a sectoral systems framework, innovation is considered to be a process that involves systematic interactions among a wide variety of actors for the generation and exchange of knowledge relevant to innovation, and its commercialization is influenced by institutional conditions (Malerba and Adams 2014).

From this perspective, innovation can be understood as a co-evolutionary process of knowledge/technological and institutional developments (Nelson 1994, 1995). Knowledge at the base of innovative activities changes over time and affects the boundaries and structure of the sectoral innovation system. Actors and networks are highly affected by the characteristics of and changes in the knowledge base. Any such changes in the knowledge base or demand affect the characteristics of the actors, the organization of research and development (R&D) and the innovative process, and the type of networks, as well as the structure of the market and the relevant institutions. These variables, in turn, lead to further modifications in the technology, the knowledge base, and demand. In the emergence of the knowledge-based economies, the focus has been on the role of the main actors in the innovation system—namely, universities, firms, and the government—and their relationships and interactions within the innovation system. The experience of the last decades, however, has shown that other influences, such as activities by end users and discourses in society, can also play an important role in driving innovation.

To investigate the broad societal structures and processes, the technological innovation system approach is effective in capturing the activities directed toward development, diffusion and use of a particular technology (Bergek, Jacobsson, Carlsson et al. 2008). A technological innovation system is defined as networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilize technology (Carlsson and Stankiewicz 1991). It is important that the analysis of the functions should receive the most attention, as the aim of a technological innovation system is to fulfil its functions, rather than to achieve a structure (Bergek, Carlsson, Jacobsson et al. 2008).

The functions identified for a technological innovation system include knowledge development and diffusion, guidance of the search, entrepreneurial experimentation, market formation, creation of legitimacy, resource mobilization, and development of positive externalities (Bergek, Carlsson, Jacobsson et al. 2008). Knowledge development and diffusion can be considered as one of the core functions of a technological innovation system, encompassing the creation of different kinds of knowledge including scientific, technological, market and logistic knowledge. Guidance of the search refers to the way in which society creates incentives for a certain type of technology to emerge, and if this function is performing well, there is a clear common understanding of the expectation and probabilities of technology development and diffusion, which is shared by industry actors, the government and consumers. This is particularly important as it addresses the often-overlooked phase of interactions among different groups of interest and power within innovation processes (Smith, Stirling, and Berkhout 2005). While a less precise vision could be helpful in mobilizing a broad coalition, if the interpretative flexibility is too great, the innovation system would not be pulling in the same direction and therefore not be effective as a system.

Entrepreneurial experimentation refers to experiments carried out by actors expecting to be able to use the technology to achieve their aims, and these activities are at the forefront of the innovation process. While emerging technologies often initially have very small and weak markets, for the benefits of innovation to become widespread, markets with potential profits need to be formulated. Creation of legitimacy refers to the process in which the technology becomes socially accepted and better integrated into the legal system. When this function is not fulfilled, societal guidance and market creation would be unlikely to occur as well, and regulatory barriers can create obstacles to innovation.

Normally, innovation requires different kinds of resources in order to proceed, and the availability and accessibility of these resources, including financial and human capitals, are critical in promoting innovation. For a technological innovation system to be successful, the existence of complementary technologies is often important, as their developments reinforce each other. As part of efforts to find ways to accelerate and enhance innovation processes, the technological innovation system approach has mostly been applied to the study of green innovation, which is aimed at addressing societal values of environmental protection and sustainability. Examples include wind turbines (Kamp, Smits, and Andriesse 2004), renewable energy systems (Jacobsson and Bergek 2004), and renewable vehicle fuels (Suurs 2009).

The innovation system of smart cities involves complex interactions of advanced technologies for an efficient, flexible, and resilient energy supply and applications, as well as the behavior of the actors, including electricity generators, distributors, technology developers, and end users. To capture a broad understanding of the processes of introducing and implementing innovation for smart cities in Japan, we analyze the major actors in academia, industry, and the public sector with specific knowledge and technological domains concerning smart cities, and the institutional conditions and environments in which these stakeholders interact. We also examine the drivers or obstacles in innovation by paying attention to the functions of the innovation system of smart cities.

3. Analysis of the Japanese Innovation System for Smart Cities

3.1 Institutional Development

The Japanese government interest in smart cities grew out of the government's promotion of renewable energy sources, an area in which Japan was an early champion. In the first decade of the millennium, the New Energy Development Organisation (NEDO), a governmental agency under the Ministry of Economy, Trade and Industry (METI), promoted domestic projects aiming at developing grid-connecting technologies for renewable energy projects. Projects attracting support included clustered photovoltaic (PV) generation, mega-solar generation, wind power stabilizing and power quality management, and micro-grids. Although these projects were not necessarily carried out under the label of smart cities, they touched upon some of the functionalities now associated with the concept of smart cities. In 2010, smart city innovation efforts commenced when METI launched four large-scale smart city demonstration projects in different areas of Japan. These were called "Next-Generation Energy and Social Systems Demonstration Areas," later known as "Smart Communities." The projects are all based around the important role of local authorities, with one coordinating corporation per project. This corporation receives support from METI and coordinates with other partners. It focuses on creating practical examples of different smart energy technologies (METI 2015b). Other innovative efforts for smart cities in Japan have been mainly conducted by potential vendors of smart grid technologies, often in collaboration with other enterprises such as real estate developers.

Many government organizations are involved in the Japanese innovation system of smart cities. Among these, METI is the most prominent actor, with a broad portfolio of relevant policy areas. Traditionally characterized by a strong relationship with the business sector, METI's main mission has been to support the development of Japanese industry. Situated under METI, the New Energy and Industrial Technology Development Organization (NEDO) is

Japan's largest public R&D funding and management organization. As one of the responses from the government to the oil crisis of the 1970s, NEDO was formed in 1980 to promote the development and diffusion of new energy technologies in Japan. Prior to the year 2000, NEDO-supported research on electricity grids focused on extending grid connections to single producers of renewable energy. In the first decade of the new millennium, NEDO shifted its focus to the inclusion of large-scale, multiple renewable energy producers. Since 2010, a broader focus has been made on the concept of 'smart communities', with more attention to consumer-domain technologies (Morozumi 2010).

METI and NEDO conduct their efforts toward innovation for smart cities in close collaboration with the business sector. Local governments, especially the cities that were allocated financial resources through the Japan Smart Cities project and the Future Environment City project, are very active in smart city activities. Several cities have partnered with private companies or universities—for example, the city of Fujisawa is partnering with one of the largest electronic companies in Japan, Panasonic; and Toshima ward in Tokyo has collaborated with the Tokyo Institute of Technology (Tokyo Institute of Technology 2012).

The most important actors in Japanese efforts toward smart cities are large firms with strong corporate networks and technological knowledge, such as Hitachi, Toshiba, and Mitsubishi. The size of these companies and their networks with other firms provide them with access to expertise in various aspects of smart city technologies (Office of Energy and Environmental Industries 2012). Because of their large portfolios of business activities, these companies tend to take a broader definition of smart cities, with many products and services available for residential end-users of electricity. Companies and consultancies in the information and communication technology sector are also active, mostly in the development and provision of software components and services. Residential developers and department stores are also important stakeholders, as they aim to provide customers with additional services and the potential for cost reductions through the installation of smart energy technologies.

The Japan Smart Community Alliance (JSCA) was formed in April 2010 by METI and NEDO, which hosts the secretariat. This followed the recommendation from an internally produced roadmap that international standardization efforts were needed. By February 2013, 408 companies had joined the organization, with Toshiba serving as the president (Japan Smart Community Alliance 2013).

The Energy Conservation and Homecare Network (ECHONET) Consortium is a network of private companies in the area of smart housing. Active since 1997, the consortium has been established to develop communication standards for smart appliances—which are open and universal—to promote the emergence of home networks connected to these smart appliances (ECHONET Consortium 2013a). As of January 2013, the consortium has eight core members representing some of the largest electronics producers in Japan, including Panasonic, Sharp, and Toshiba, as well as Japan's largest utility company, Tokyo Electric Power Company (TEPCO) (ECHONET Consortium 2013b). After its establishment, ECHONET experienced a steady decline in activities in the early 2000s, as consumer interest in smart appliances remained quite low, and the proliferation of communication protocols meant high costs and uncertainty for vendors. In 2011, the consortium developed technologies in the area of home appliances and equipment into the ECHONET Lite Specifications, a standard that can work with standard protocols in Japan and abroad. The home energy management system (HEMS), a system for managing the various types of energy used in the home in smart ways, makes data on the amounts of electric power generation and utility usage—as well as gas and water used—visible on monitors and other screens. This facilitates smart control of HEMS-compatible home appliances and household devices. The ECHONET Lite Specifications provide the function of shared communication protocols that are necessary to achieve two-way communication between HEMS controllers and various home appliances, household devices, etc. With HEMS controllers adopting ECHONET Lite and devices compatible with HEMS, it becomes possible for different manufacturers' products to be connected together for use. ECHONET Lite was recommended as an open standard interface on HEMS by the International Standardization Working Group of JSCA, which promoted an increase in interest and membership in the ECHONET consortium.

In some areas, local associations have been established for private companies and research institutes that are involved in smart city or smart house developments. One example is the Yokohama Smart Community Association, which was created following the beginning of the Yokohama Smart City project. It is an association of local small and medium enterprises (SMEs) working in collaboration with smart city initiatives and acting as suppliers for some of the companies involved (Uetake 2013).

3.2 Network of Actors Working on Smart Cities

The innovation system of smart cities in Japan can be analyzed by identifying major actors and their relationships and incorporating their knowledge and technological domains concerning various aspects of smart cities. Data was collected on projects and consortia related to smart cities through trade journals, research reports, web sites, and interviews with relevant stakeholders. As a result, a database was constructed with 22 projects and two consortia. Network analysis was conducted to identify key stakeholders in the Japanese system of innovation of smart cities and to analyze the relationships between them. In the network, when multiple organizations join the same joint project, they are connected with one another. A social network was constructed with the software UCINET (Borgatti, Everett, and Freeman 2002). The details of the data and procedure of UCINET analysis are explained in the Appendix (prepared soon).

Table 1 lists key actors in the network involved in the innovation system of smart cities in Japan. They are listed in the order of the most-connected organizations according to the measurement of 'betweenness centrality',**38** which illustrates how important the location of an organization is for the other organizations connected with each other in the network. The table also shows the 'degree centrality', which measures the number of connections to the organization.

Table 1: Key Actors in the Innovation System of Smart Cities in Japan

Organization	Sector	Betweenness Centrality	Degree Centrality
Hitachi	Electronics company	5212.7	74
Toshiba	Electronics company	3735.6	64
Mitsubishi Corporation	Trading company	2908.3	67
NEDO	Governmental funding agency	2735.7	28
Sharp	Consumer electronics company	1603.5	91
Denso	Automotive component supplier	1567.2	55
Fuji Electric	Infrastructure provider	1516.7	53
JX Nippon Oil & Energy	Petroleum company	1481.1	55
Panasonic	Electronics company	1276.7	35
Furukawa Electric	Infrastructure provider	1187.1	47
University of Tokyo	University	1154.3	13
Sumitomo Electric Industries	Infrastructure provider	1123.1	55
Urban Renaissance Agency	Real estate agency	960.8	47
TOTO	Whiteware company	917.4	30
IBM	Software provider	917.4	30
Omron	Electronic component supplier	770.8	24
Kansai Electric Power Co.	Electric utility	770.8	24
Iwatani	Gas equipment provider	658.8	29
Nittetsu Elex	Infrastructure provider	658.8	29
Tokyo Gas	Gas utility	609.8	31

As can be seen from **Table 1**, the key actors identified in the network analysis are mainly large conglomerates with broad portfolios, covering both electronics and infrastructure areas. They are also members of both JSCA and ECHONET and are participating in several demonstration projects. The top two, Hitachi and Toshiba, are of particular importance, with the government funding agency NEDO also playing a prominent role in the network. The large electric utilities, on the other hand, are not centrally connected to the network, and their presence is relatively invisible.

Reflecting the key actors in the innovation system of smart cities, the important knowledge domains are related to energy and power systems. Other knowledge and technological domains include renewable energy, distributed energy and energy storage, distributed generation, the creation of new service markets, EV charging infrastructure, and energy storage and security. Knowledge and technological domains related to application sides—including smart housing—are relatively well-represented.

3.3 Analysis of the Functions of the Innovation System of Smart Cities

In this section, the innovation system of smart cities in Japan is examined by looking at the functions that would be expected to work in facilitating innovation. The financial resources provided by METI and NEDO to relevant projects have functioned as an important stimulus for innovation, especially through funding the smart city projects. After the Fukushima accident, in particular, many of the electric utilities have relatively limited financial capabilities to initiate and implement new technological development. This has directly affected their engagements on pre-existing smart city initiatives. The activities of the electric utilities that are still on-going are mostly funded by government grants, which illustrates the significant role played by resource mobilization for keeping the momentum on innovation.

The function of entrepreneurial experimentation has been performing relatively poorly in Japan. While established manufacturing firms are making efforts to tap into new markets, the traditional monopolistic structure of the electricity market and the uncertainty about future policies and regulations have discouraged ambitious activities of entrepreneurship. Moreover, the membership in the smart city projects has remained relatively closed, with new entrants very limited, and the area of smart cities has come to be regarded as a field that gives advantage to the established industrial giants. The smart house and appliance sector sees more involvement and engagement by smaller firms in addition to the large electronic companies.

Currently, the goal of creating a market for technologies related to smart cities in Japan is facing many problems and challenges. While a very limited market exists at present, it is still at a very tentative stage, and the uncertainties surrounding the current environment and future development of the electricity market are likely to make potential investors wary. In the housing sector, the market has developed further, and some demand is already emerging. Residential developers have played a key role in popularizing various applications for smart home and appliances, including smart electric energy meters, which digitally measure electricity usage. These automatically send measured data to power companies, communicating with HEMS controllers via ECHONET Lite for electricity usage status in a visible form that is based on the meter readings used for billing. The residential developers, however, while actively engaged with the concept of smart home and appliances, only cater to upper-income groups, with HEMS remaining relatively expensive. The high prevalence and popularity of residential photovoltaics in Japan has also been an important driver in the smart house market.

The creation of legitimacy has not been a serious problem in facilitating innovation for smart cities in Japan. Although knowledge about smart cities is not widely shared among the general public, energy security and efficiency are generally understood as areas that need to be supported since the oil crises in the 1970s. Hence, the planned outages by the electric utilities following the Fukushima accident led to strong criticism, as regions of less economic importance had to endure more blackouts. Accordingly, smart energy technologies that are considered to contribute to reducing energy consumption are socially accepted, without much resistance due to concerns about privacy or health effects. In the housing sector, the situation has been less problematic, as smart appliances are better appreciated by consumers due to the benefits that these technologies provide.

The development of positive externalities has also been important in the evolution of technologies for smart cities. A crucial area of co-evolutionary development is the fast-developing field of smart home and appliances. The appliance manufacturers who also have interests in the grid equipment market have been the most active stakeholders in the technological innovation system for smart cities. Furthermore, the electric vehicle has been an innovation area of critical importance. While currently at too early a stage to contribute significantly, the development and diffusion of electric vehicles will benefit considerably from smart city innovations. Renewable energy development has also been an adjacent innovation area. The influence of renewable energy is still relatively small, however, as the electric utilities currently allow only limited amounts of electricity to be connected to the grids. This is due to concerns about the grid capacity to absorb the fluctuations and interruptions in the electricity produced from renewable energy sources, particularly solar power.

In Japan, the situation in regard to the knowledge creation and diffusion process can be considered as positive. Smart city projects are regarded as especially important collaborative platforms in which novel technological functionalities can be tried out. While the tightly knit groups involved in the smart city projects are producing valuable knowledge, the sharing of that knowledge has been relatively limited. Within the smart house and appliances sector, knowledge creation has proceeded further, and diffusion platforms have been seen as better developed. This is especially the case since the Fukushima accident, after which the government started to promote standardization and to provide financial support to consumers for purchasing home energy management systems (HEMS).

The process of the guidance of the search has been performing relatively well, as there is a shared understanding about the basic concept and acceptance of smart cities, although the emphasis varies to a certain extent between different stakeholders. NEDO has been regarded as the most important actor in facilitating consensus building among the key stakeholders involved in smart city development (Morozumi 2012). NEDO was established in 1980 and reorganized in 2003 as an incorporated administrative agency under the Ministry of Economy, Trade and Industry. Initially, NEDO primarily focused on supporting the development of specific technologies related to renewable energy and energy saving. In the year 2000, multiple large-scale demonstration projects were initiated with renewable grid-connecting technologies. Since 2010, smart community demonstration projects have started to incorporate wider societal needs concerning smart cities. As the public sector manages the financial resources for many of the demonstration projects for smart cities, it has a significant capacity to influence the focus and direction of the development of technologies relevant to smart cities.

4. Implications for Public Policy and Institutional Design

4.1 The Importance of the Energy Management System (EMS)

As an important component for developing smart cities, large-scale induction of renewable energy requires us to maintain a high quality of electricity in terms of voltage and frequency. After the Fukushima accident, it has also become critical to save energy and cut back consumption during peak periods. As new technologies concerning energy supply and distribution are emerging, their safety and reliability need to be tested and verified. Smart cities are expected to improve energy efficiency and facilitate energy resilience by utilizing advanced technologies, including ICTs and storage batteries, with cogeneration and renewable energy through distributed energy systems.

Given this background, there are several objectives that can be identified for promoting smart cities in Japan. First, it is of critical importance to strengthen the resilience of the energy supply against future disruptions and disasters such as earthquakes and typhoons through distributed energy systems. At the same time, we need to reduce the environmental burden, including carbon dioxide emissions, by increasing renewable energy sources and efficient energy usage. Efficient and resilient energy systems require the effective utilization of energy management systems (EMSs), including demand-response systems to manage the balance between energy supply and demand efficiently through consumer participation in cutting energy consumption during peak periods. It should also be possible to reduce the capacities of thermal power generation prepared for peak energy consumption by establishing efficient electricity systems from a mid- to long-term perspective.

4.2 Introduction of the Feed-in-Tariff (FIT) Program

There are several policy approaches and instruments that are considered to have influenced the development of smart cities in Japan. They include liberalization of energy markets for new entrants; a feed-in-tariff (FIT) program for promoting renewable energy; technological road-mapping to social system demonstration; localization of demonstration projects adjusted to economic environments, major actors, and technological orientation; platforms for strategic partnerships among stakeholders including academia, industry, government, and local communities; and standard setting for smart meters and equipment.

The Japanese government has recently started to introduce a series of policy measures to accelerate the liberalization of energy markets (METI 2015a). One is the Amended Electricity Business Act enacted in November 2013. This legislation established the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) in 2015 to promote wide-area electrical grid operation. The liberalization of the retail sale of electricity was initiated in April 2016. Furthermore, separation of power generation and power transmission is expected to take place in 2018-2020. Another policy measure is the Strategic Energy Plan introduced in April 2014. This plan has accelerated the introduction of renewable energy sources. For example, it is expected that the energy produced by photovoltaics will be increased to 53 GW and by wind to 10 GW by 2030. A strong emphasis has been placed on R&D and demonstration of transmission and distribution equipment. It is also specified that regional or interregional grids for renewables will be established.

The policy instrument of FIT was very important for promoting the adoption of renewable energy sources. The shutdown of nuclear power plants following the Fukushima accident in March 2011 has effectively accelerated the expansion of renewable energy as a strategy to make up for lost power generation and to reduce Japan's dependence on imported oil and natural gas. The government announced in June 2011 a target of putting PV systems on the top of 10 million roofs by 2030. The FIT program was introduced in 2012 to encourage the installation of renewable energy, particularly solar PV. Revised FIT for PV is expected to account for more than 80% of newly installed capacity in the coming decade. On the other hand, while capacities of more than 80 GW of solar power have been approved, only those of 23 GW had been installed by the end of 2014. Consequently, installations of PV have slowed as utilities have denied additional grid access to new solar farms. The current grid infrastructure has not been set up for large-scale adoption of renewables such as solar and wind power, with further deployment disrupting the operations of the grid.

The gradual shift from technological road-mapping to social system demonstration was also important in facilitating systemic approaches to innovation for smart cities. Iterative processes of revising the technological roadmap on PV were conducted by the funding agency NEDO (NEDO 2014). The NEDO PV 2030 roadmap was initially published in 2004. This road map was subsequently revised in 2009 as NEDO PV 2030+ and again in 2014, when it was given the title NEDO PV Challenges. In this process, the main focus has been on technological development. **54**However, the support provided by NEDO has shifted gradually from technological development to social system demonstration. Prior to 2000, the funding agency mainly supported the development of specific technologies for introducing renewable energy to the electricity grid. In the period from 2000 to 2010, support was provided for the development and demonstration of multiple, large-scale technologies coordinated for introducing renewable energy to the grid. Since this time, however, the demonstration of smart cities that incorporate a focus on meeting social needs has been encouraged with financial assistance.

4.3 Pilot Trials of Smart Cities in Local Governments

Demonstration of smart cities in various parts of the country has been critical for testing promising technologies and raising awareness among the general public. Smart city projects were implemented in the four cities of Yokohama, Toyota, Keihanna, and Kitakyushu in the period from 2011 to 2014 (METI 2015b). They were mainly aimed at verifying emerging advanced technologies concerning smart cities, including cogeneration, renewable energy, energy storage, electric vehicles, and energy management systems. At the same time, these projects were also aimed at establishing robust business models with the active participation of relevant stakeholders, including local communities and residents, as well as technology providers in the private sector.

What was important in implementing these demonstration projects is that they were locally adjusted, considering the specificities of the economic and social conditions and contexts. In Yokohama, which is a major metropolitan city close to Tokyo, the aim was to facilitate the large-scale introduction of renewable energy and electric vehicles, with the participation of 4,000 households equipped with HEMS, ten large-scale buildings, and multiple storage batteries. In Toyota, local production of energy for consumption locally was the target, involving 67 households equipped with solar panels, household fuel cells, storage batteries, and advanced transportation systems including electric vehicles and plug-in hybrid vehicles. Keihanna Science City tested the visualization of energy for control and management in a housing complex of 700 households and HEMS and the feasibility of consulting business on energy saving. In Kitakyushu, which has a designated energy supply area, optimization of various sources of energy was explored, with power supplied by large steel and metal companies and a dynamic pricing system introduced for 180 households.

These demonstration projects had the significant effect of accelerating technological integration, reliability, and learning through trial and error. For establishing smart cities, various types of new promising technologies need to be verified, adopted, and integrated, including facilities for renewable energy, energy storage batteries, and energy management systems. As it is usually difficult to show the economic advantages of emerging technologies over conventional energy systems, their deployment for smart communities would be at a disadvantage under normal conditions. Through these demonstration projects, large-scale adoption and intensive learning become possible, leading to a decline in the prices of component technologies and the costs of operating energy systems.

4.4 National Standard Setting

Standard setting for component technologies, particularly smart meters, also played an important role in facilitating the introduction of smart cities. Proprietary standards among competing providers initially slowed down the takeoff of the market. The Open Automated Demand Response (OpenADR) 2.0 technology standard was adopted—following feasibility, interoperability and connectivity testing—in the summer of 2013 (Ishii 2015). With an application programming interface (API), the efficient development of applications was also promoted, including HEMS and building energy management system (BEMS). The adoption of HEMS had a significant impact on driving Japan's smart household appliance industry, with LED lights, smart thermostats, plug-in electric vehicles, rooftop solar, demand-flexible water heaters, battery energy storage, and other appliances now integrated within the IT network. The HEMS Alliance has been formed by leading companies to create a multi-vendor device environment. On the other hand, new standards have recently started to emerge in other sectors, particularly in fields related to what is called the Internet of Things (IoT), in which virtually everything will be connected for information exchange and communication so that many activities that were formerly conducted separately can now be coordinated with each other efficiently. Various standards—such as ZigBee and Bluetooth Low Energy—are currently under rapid development, leading to an urgent need to consider cooperation and coordination among the major players.

5. Concluding Remarks

In this paper, the innovation system of smart cities in Japan is analyzed. The analysis reveals a concentrated structure dominated by large well-established actors in the public sector and the electric and electronics industries, with knowledge and technological domains primarily focusing on renewable energy, energy storage, community energy management, and applications for home appliances and electric vehicles. The policies and regulations that influenced the innovation system of smart cities include economic incentives to promote renewable energy technologies, liberalization of energy markets for new entrants, participatory processes of road-mapping on key technologies, localization of demonstration projects reflecting specificities, standard setting for component technologies, and platform creation for stakeholder partnerships including academia, industry, government, and civil society.

At the same time, several challenges in implementing system transformation for urban sustainability still remain. There needs to be a clear vision of what kinds of smart cities should be established that can be matched to feasible plans for implementation. Strong leadership for projects and transparency in the process of decision making and implementation are also important. In this respect, universities, in particular, are expected to play a key role in generating concrete solutions and strategies to tackle the dynamic, complex challenges in smart cities

(Yarime et al. 2012). To this end, utilizing universities as a platform for social experimentation through collaboration and networking among academia, industry, and the public sector will enable contributions to learning and innovation for urban sustainability.

The experience and expertise of the private sector are also a particularly crucial ingredient when implementing multi-stakeholder collaborations with the public sector aimed at triggering institutional reforms favoring innovation for smart cities. Robust business models are currently missing, which has the effect of discouraging private companies from taking over the demonstration projects that have mainly been financed by the public sector. It is also critical to nurture human resources with skills and capacities necessary to understand and integrate technical and societal dimensions of smart cities. While large established companies tend to have advanced technological expertise and capabilities concerning various instruments and facilities in smart cities, local governments and communities do not necessarily possess sufficient knowledge or experience of dealing with technical measures (Yarime 2017). Under the existence of the significant degree of asymmetry of knowledge and expertise between large technology companies on the one side, and local government and communities on the other side, we need to consider how it would be possible to secure serious and active participation of **63**end users in an equal and equitable manner for jointly facilitating innovation. As smart cities consist of various types of hardware and software, coordination among different standards is also indispensable for facilitating the development and adoption of technologies for smart cities.

Policy measures and instruments need to be well-coordinated in an institutional landscape at the macro level, while the same needs to be done for specific technologies at the micro level. This is particularly important for the creation and liberalization of energy markets in encouraging new entrants and entrepreneurship and consequent competition, as this study has shown. Participatory processes of road-mapping of technological development to social system demonstration evolve through up-to-date and diverse inputs from relevant stakeholders.

Standard setting needs to be carefully managed for facilitating connectivity among the existing technologies while paying close attention to emerging technologies in related fields.

Located at the complex intersection of economic development and environmental change, cities play a central role in our efforts to move towards sustainability. Currently over half of the world's population live in urban areas, and more than two-thirds of the world's population are expected to be urbanized by 2050. While cities are the engines of economic growth, accounting for a significant part of global energy consumption, they are at the same time producing harmful pollutants and greenhouse gas emissions and vulnerable to natural disasters. These issues are interconnected with one another, with their dynamic interactions changing in highly complex and unpredictable manners. Reducing air and water pollution and improving energy efficiency while securing energy supply and maintaining resilience to disruptions and disturbances would be a formidable task. It is hoped that Japan's experience of facilitating innovation for smart cities will provide useful lessons and implications for addressing the sustainability challenge across the globe.

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Abstract (in Japanese)

要約

スマート・シティは、都市のサステイナビリティに向けた我々の努力において、非常に重要な役割を果たす。スマート・シティは都市の様々な機能に関わるハードウェアとソフトウェアの高度なシステムであるため、そこで生まれるイノベーションは知識、アクター、制度の側面において大きな多様性が考えられる。したがって、スマート・シティのイノベーション・システムの特徴を理解し、それに基づいてイノベーションを促進するための政策を導入することが重要である。本ペーパーでは、日本におけるスマート・シティのイノベーション・システムを検証し、公共政策、制度設計へのインプリケーションを議論する。日本におけるスマート・シティのイノベーション・システムは、特に公的セクターと電機電子産業における比較的規模の大きい組織が中心的な役割を果たしており、知識・技術ドメインとしては、再生可能エネルギー、蓄電池、コミュニティ・エネルギー・マネジメント、家庭用器具、電気自動車などが関わっている。スマート・シティのイノベーション・システムへ影響を及ぼす政策・規制としては、再生可能エネルギーを促進するための経済的なインセンティブ、エネルギー市場の自由化を通じた新規参入の促進、重要な技術に関するロードマッピングの繰り返し、地域の特性を反映したデモンストレーション・プロジェクト、要素技術の標準化、大学、産業、政府、市民社会を含むステークホルダー連携のためのプラットフォーム形成などが挙げられる。特に公共政策にとって重要な点は、エンド・ユーザーとのコミュニケーションと関わりを促進して、スマート・シティに向けたイノベーションを共同で進めていくことである。

キーワード：スマート・シティ、イノベーション・システム、ネットワーク分析、ステークホルダー連携、日本

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