Understanding the Innovation System of Smart Cities: The Case of Japan and Implications for Public Policy and Institutional Design

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Abstract

Smart cities are one of the key areas in which innovation will make a significant contribution to implementing system transformation towards sustainability. Smart cites are based on advanced systems of hardware and software for mutual exchanges of energy and information between supply and demand sides. They require effective integration of a variety of science and technological knowledge through collaborating with various stakeholders in academia, industry, and the public sector. Therefore, innovation systems of smart cities exhibit a significant degree of diversity in knowledge, actors, and institutions. In this paper, we examine the innovation system of smart cities in Japan and its implications for system transformation towards sustainability. Bibliometric analysis of scientific and project documents in Japan reveal that knowledge domains basically concern renewable energy, energy storage, community energy management, and applications for home appliances and electric vehicles. Network analysis of actors suggests a concentrated structure dominated by large actors, particularly government organizations and electric and electronic companies. Policies and regulations influencing the innovation system for system transformation include economic incentives to promote new technologies, liberalization of markets for new entrants, iterated 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 end users. Policy and institutional measures for facilitating communication and engagement with end users would be particularly important for implementing innovation.

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

1. Introduction

Smart cities are considered as a key area where innovation plays a critical role in making system transformation towards sustainability. Smart cites are based on advanced systems of hardware and software for mutual exchanges of energy and information between supply and demand sides for efficient, flexible, and resilient services, incorporating the behavior of different actors including generators, distributors, technology developers, and consumers through an intelligent network. Improvement in the efficiency of energy consumption will reduce emissions coming from energy generation, particularly those from coal power plants. Flexibility in balancing energy supply and demand through smart meters and affiliated technologies will facilitate the introduction of renewable energy sources such as solar and wind, substituting pollution-laden fossil fuels. Electrification of urban infrastructure will also support the deployment of electric vehicles, which do not emit pollutants unlike the conventional vehicles driven by internal combustion engines.

As a diverse mixture of hardware as well as software are involved in a complex way, however, a variety of approaches would be possible to implementing the concept of smart cities in practice. Therefore, innovation systems of smart cities exhibit a significant degree of diversity in knowledge, actors, and institutions, depending on the economic, social, and environmental conditions. In-depth examination of the processes of creating innovation on smart cities is expected to generate useful lessons for implementing system transformation. Policy and strategic implications of the experiences of the industrialized countries will be particularly important for many countries in the developing world, where urbanization is proceeding rapidly in many major cities, producing many energy and environmental challenges. They require effective integration of various types of science and technological knowledge through close collaboration with relevant stakeholders in academia, industry, and the public sector.

In this paper, we examine the innovation system of smart cities in Japan and its implications for system transformation towards sustainability. This research is aimed at understanding the processes of implementing innovation on smart cities in the economic and social contexts of the country. Detailed analysis is conducted on what knowledge and technologies are focused on, what actors are involved at which stages of innovation, what factors influence the behavior of the actors, and what effects and impacts are made by policy interventions. Projects on smart cities are analyzed in terms of the actors involved, the technological areas emphasized, and the processes in which the actors collaborate with each other. Information was collected through various sources, such as project reports, academic articles, corporate reports, trade journals, and web sites, and interviews were conducted with relevant stakeholder, including academia, firms, industry association, and government organizations. Network analysis is conducted to identify key stakeholders involved in innovation on smart cities and to analyze the relationships between them, illustrating how important organizations are located and interacted in the communities on 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 the analysis of the experience of Japan, implications are discussed for policy measures and approaches for making system transformation towards sustainability.

2. Innovation Systems of Smart Cities

Smart cities are widely seen as a future trajectory of technological change in the energy system. In smart cities a key role is played by smart grids, which would 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). Bundling various types of equipment and practices, smart grids constitute an aggregate system to improve electricity generation, distribution, and consumption by introducing new functionalities. Based on smart grids, smart cites have been evolving into sophisticated systems of hardware and software assembling and processing an increasing amount of information on multifaceted dimensions of cities, providing diverse types of products and services.

The concept of smart cities, therefore, would reflect different dimensions of complex technological assemblages, and as such there are significant differences in the nuance and emphasis of the concept, depending upon the specific contexts and conditions. In Europe a focus is given 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 a more intelligent way (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 the functionalities discussed as part of the smart city are many, there is also a breadth of benefits envisioned for society when a smart city is implemented. Potential benefits include higher overall energy efficiency, lower cost of operating the electricity grid, lower environmental impact, higher resilience of the energy system and more empowerment to end-users in the energy system. Given the desirability of these benefits for societies facing climate change and increasing energy prices, and the high hurdles such a complex systemic technology area faces, it is important that governments facilitate the introduction of smart cities. This study takes a systemic approach to examining the experience in Japan to extract valuable lessons and implications for governments and entrepreneurs seeking to promote smart cities.

This study takes a holistic approach to examining the processes of innovation on smart cities. Given the relatively short period of time in which smart cities have evolved, there have not been many studies with macroscopic views to innovation on smart cities, particularly those studies conducted from policy perspectives (Lin, Yang, and Shyua, 2013). One of the major analytical approaches to studying innovation processes is the approach of innovation systems. It has been built upon the notion that not only activities by firms and researchers determine the character of technological change, but also 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).

For understanding the characteristics of innovation in a particular sector, it would be useful to identify a sectoral innovation system. A sectoral innovation system is understood to consist of three main dimension: namely, knowledge, actors, and institutions (Malerba, 2002, 2004). The knowledge dimension deals with the specificities of knowledge and technological domains that are relevant to the innovation. The actors involved in the innovation system show heterogeneity, networks, and interactions among 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 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. And changes in the knowledge base or in demand affect the characteristics of the actors, the organization of research and development (R&D) and of the innovative process, the type of networks and 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, a focus has been placed 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 have an important role in driving innovation.

To investigate broad societal structures and processes, the approach of technological innovation system would be effective in capturing the activities directed toward development, diffusion and use of a particular technology (Bergek, Jacobsson, Carlsson, Lindmark, and Rickne, 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 stressed that it is the analysis of the functions that 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, Lindmark, and Rickne, 2008). The functions identified include knowledge development and diffusion, guidance of the search, resource mobilization, entrepreneurial experimentation, market formation, legitimation, and development of positive externalities. In efforts to find ways to accelerate and enhance innovation processes, the approach of technological innovation system has mostly been applied to the study of green innovation, which is aimed at addressing societal values of environment 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 would involve complex interactions of advanced technologies for efficient, flexible, and resilient energy supply and applications and the behavior of the actors including generators, distributors, technology developers, and end users. To capture a broad understanding of the processes of introducing and implementing innovation on smart cities in Japan, we analyze the knowledge and technological domains concerning smart cities, the key actors and stakeholders including academia, firms, industry association, and government organizations, and the institutional conditions and environments in which these stakeholders interact and examine the drivers or obstacles in innovation by paying attention to the functions of the innovation system of smart cities.

3. The Case of Japan

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 supported 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 started 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 on an important role of local authorities and one coordinating corporation per project, which receives support from METI and coordinates with other partners, and focus on creating practical examples of different smart energy technologies (Uetake, 2013). Other innovative efforts on 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.

3.1. Knowledge and Technological Domains

Knowledge is a major driving force of development and transformation in economic systems, and learning and knowledge by individuals and organizations are at the base of innovation. Therefore, to understand the characteristics of the innovation system of smart cities, it is important to analyze what kinds of knowledge and technologies are involved. Bibliometric analysis was conducted on the academic articles concerning smart cities in Japan. The result is visualized as a semantic network, where more commonly occurring words are represented with larger nodes, and a connecting edge between two words in close positions means a high level of their co-occurrence (Vlieger and Leydesdorff, 2010).

Figure 1 shows the knowledge and technological domains in the innovation system of smart cities in Japan. The most important knowledge domains were found to be energy system and power system. The concept of smart grid concept, although not at the core of the network, occupies a relatively central role. Other core 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. There are some close relationships, for example, among home, service, and consumption, probably related to smart home functionalities. Concepts such as social, cost, load, reduction, reserve, and optimal form a separate cluster, probably showing an interest in economic and management dimensions of smart cities. There is also a region linking the domains like communication, information, and smart grid. It can be said that knowledge and technological domains related to application sides are relatively well-represented.

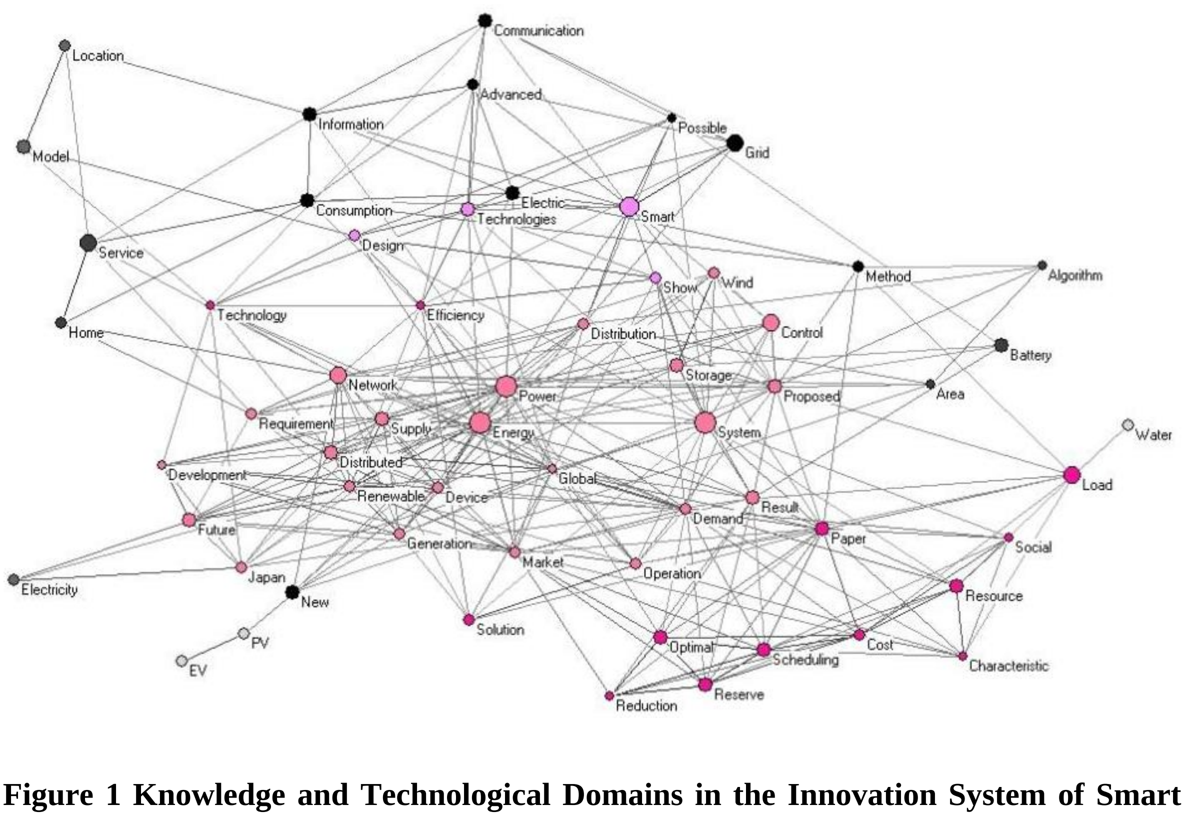

Figure 1 Knowledge and Technological Domains in the Innovation System of Smart Cities in Japan

3.2. Actors and Their Network

Many government organizations are involved in the Japanese innovation system of smart cities. Among them, METI is the most prominent actor, having 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 the 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 connection to single producers of renewable energy. In the first decade of the new millennium, NEDO shifted its focus to 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 for innovation on 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 the smart grid activities. Several cities have partnered with private companies or universities; for example, 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 (Hirai, 2013).

The most important actors in Japanese efforts on 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 grid 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 potential for cost reduction through installing smart energy technologies.

While regional monopolistic utilities have traditionally dominated most of Japan’s electricity system, they are currently operating in a very uncertain and economically difficult situation since the Fukushima nuclear accident and the liberalization of energy markets. TEPCO, the largest of the utilities in Japan and one of the largest utilities in the world, previously did not show so much enthusiasm about the concept of smart grid. Prior to the Fukushima accident, it was argued that Japanese energy system was based on the world-class technology and thus smart grids would not be very necessary (Dasher, 2012). In the post-Fukushima era, the financial standing of the utilities would make it difficult for them to make much engagement.

Japan Smart Community Alliance (JSCA) was formed in April 2010 by METI and NEDO, which hosts the secretariat, following the recommendation of a roadmap produced internally that international standardization efforts were needed. By February 2013, 408 companies have 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 developed 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, TEPCO (ECHONET Consortium, 2013b). After its establishment, ECHONET experienced a steady decline of activities in the early 2000s, as consumer interest in smart appliances remained quite low, and a proliferation of communication protocols meant high cost and uncertainty for vendors. In 2011, the consortium released an enhanced and WiFi-based standard, ECHONET-lite, which was swiftly endorsed for the home energy management system (HEMS) by the Japanese government, with financial support provided to HEMS adopting the standard. This led to a sharp spike in interest and membership in the ECHONET consortium (Mochizuki, 2013).

In some areas, local associations have been established for private companies and research institutes 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).

The network structure of the actors in the field of smart cities was analyzed by collecting data 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.

Figure 2 illustrates the entire structure of the Japanese network of the actors involved in smart city projects. **Figure 3** shows the central area of the network.

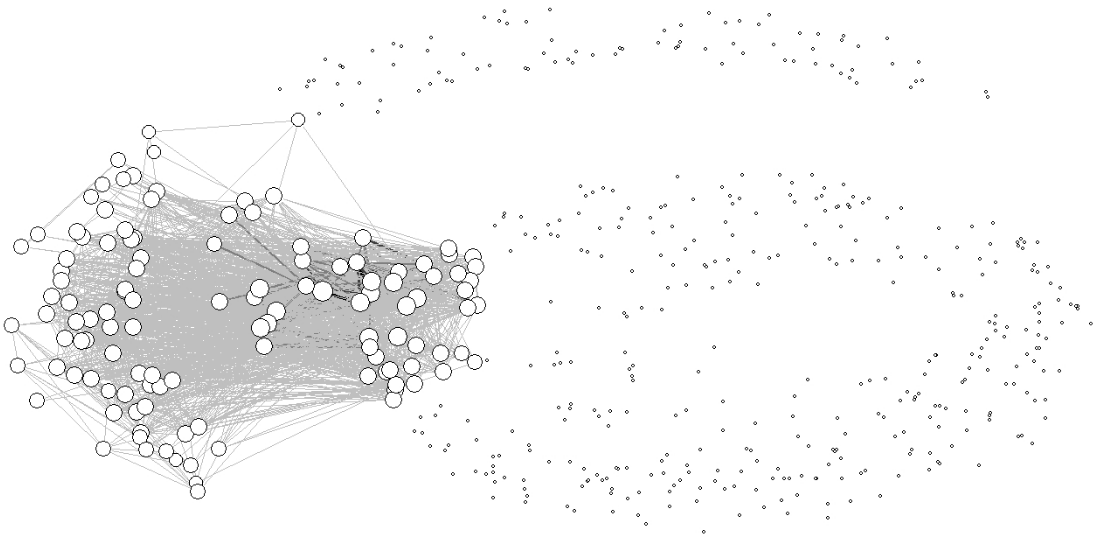

Figure 2 Actor Network of the Innovation System of Smart Cities in Japan

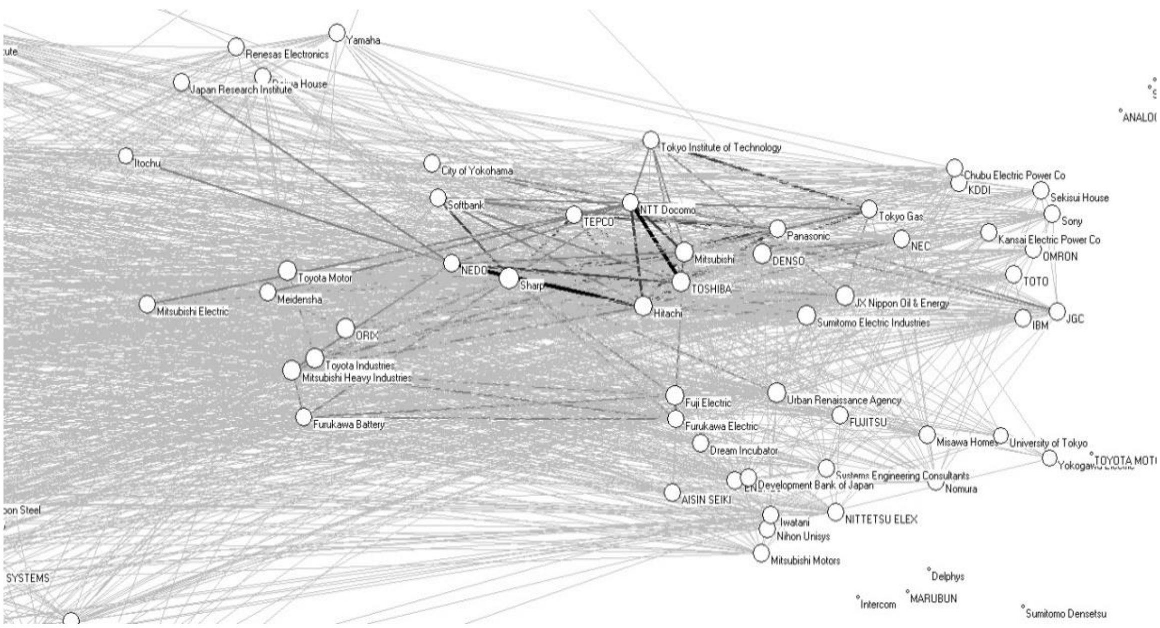

Figure 3 Central Area of the Actor Network of the Innovation System of Smart Cities in Japan

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, 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	White ware 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 **Figure 2**, **Figure 3**, and **Table 1**, the key actors identified from 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, and the government funding agency NEDO also plays a prominent role in the network. The large electric utilities, on the other hand, are not centrally connected in the network, and their presence is relatively invisible.

3.3. Functional Analysis of the Innovation System of Smart Cities

Knowledge creation and diffusion would be considered as one of the most important functions of a technological innovation system. It encompasses the creation of different kinds of knowledge concerning scientific, technological, market, and institutional dimensions. In Japan, the relevant stakeholders overall rated the situation on the knowledge creation and diffusion process as positive. The Smart City projects are regarded as especially important collaborative platforms in which novel technological functionalities could be tried out. While the tightly knit groups involved in the Smart City projects are producing valuable knowledge, the sharing of that knowledge is still limited. Within the smart house and appliances sector, knowledge creation has proceeded further, and diffusion platforms have been seen as better developed, especially 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 function of guidance of the search refers to the way in which society creates incentives for a certain type of technology to emerge from a technological innovation system. If this function is performing well, there is a clear common understanding of the expectation and probabilities of technology development and diffusion, 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 more vague vision could be helpful to mobilize a broad coalition, if the interpretative flexibility is too great, the innovation system will not be pulling in the same direction and therefore will not be effective as a system. In Japan 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 grid, although the emphasis varies to a certain extent between different stakeholders. NEDO has been regarded as the most important actor in facilitating consensus building. As the public sector manages the financial resources for many of the demonstration projects on smart cities, it has a significant amount of capacity to influence the focus and direction of the development of technologies relevant to smart cities.

Innovation requires various kinds of capital and assets for further development. Financial and human capitals are the most important among these, and the availability of these resources is crucial in enabling innovation. The financial resources provided by METI and NEDO to relevant projects has 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 smart city initiatives that had already existed. The activities of the electric utilities that are still on-going are mostly funded by government grants, which illustrate the significant role played by resource mobilization for keeping the momentum on innovation.

Entrepreneurial experimentation refers to experiments carried out by the actors who intend to utilize smart energy technologies to implement something novel for achieving their aims. Their activities would be indispensable for a process to be innovative. From a societal perspective, the experimentation of entrepreneurs would make uncertainty about the development and use of technology lower, as they create hard evidence for the likelihood of success or failure of certain types of technology. In Japan this function has been performing relatively poorly. 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 tends to be regarded as a field giving 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.

For the benefits of innovation to become widespread, a market for technologies needs to be created and well-established. As an emerging technological innovation system often has only a very small and weak market, particularly at an initial stage, a strong expectation of market formation in the future with ample possibilities and opportunities for profit making will accelerate the process of innovation. The creation of a market for technologies related to smart cities in Japan is at this moment considered to face many problems and challenges. While there exists a very limited market, it is still at a very early stage, and the uncertainties surrounding the current environment and future development of the electricity market would make potential investors wary. In the smart home and appliances sector, the market has developed further and some demand has already been emerging. Residential developers have played a key role in popularizing various applications for smart home and appliances. The residential developers, however, while actively engaged with the concept of smart home and appliances, only cater to the upper-income groups, with HEMS remaining relatively expensive. The high prevalence and popularity of residential photovoltaics in Japan has also been an important driver for the smart house market.

Creation of legitimacy refers to the process in which technologies become socially accepted and institutionally incorporated into the legal system. When this function is not fulfilled, search guidance and market formation would not be effective ultimately, and regulatory barriers can create obstacles to innovation. In the case of Japan the creation of legitimacy has not been a serious problem for facilitating innovation on smart cities. Although knowledge about smart cities is not necessarily shared widely in the general public, energy security and efficiency has basically been understood as an area to be supported since the oil crises in the 1970s. Hence the planned outages by the electric utilities following the Fukushima accident received strong criticisms, 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 smart house and smart appliance sector, the situation has been less problematic, as smart appliances are generally appreciated by consumers for the benefits to be provided by these technologies.

Empirical studies have shown that the existence of complementary innovation systems is important for a technological innovation system to be successful (Bergek, Jacobsson, Carlsson, Lindmark, and Rickne, 2008). For example, the success of civilian nuclear power technology benefited greatly from the advances in nuclear weapon technology, even though they basically belong to two distinctive innovation systems. Similarly, the development of positive externalities has also been observed in the evolution of technologies on 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 on smart cities. The electric vehicle has also been an innovation area of critical importance. While being at a too early stage to contribute significantly, the development and diffusion of electric vehicles will benefit considerably from smart city innovation. 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, because of the concern about the grid capacities to absorb the fluctuation and interruption of the electricity produced by renewable energy sources, particularly solar power.

4. Implications for Public Policy and Institutional Design

Based on the analysis of the Japanese innovation system of smart cities, we consider lessons and implications for public policy and institutional design for facilitating system transformation in the future. As an important background for developing smart cities, large-scale induction of renewable energy requires us to maintain 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 its 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 these backgrounds, there are several objectives identified for promoting smart cities in Japan. First, it is of critical importance to strengthen the resilience of energy supply against disruptions and disasters such as earthquakes and typhoons through distributed energy systems. At the same time, we need to reduce environmental burdens including carbon dioxide emissions by increasing renewable energy sources and efficient energy usage. Efficient and resilient energy systems require effective utilization of energy management systems (EMSs), including demand-response systems to manage the balance between energy supply and demand efficiently through consumers' participation in cutting energy consumption during peak periods. It would 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.

While smart cities have initially been understood as a system based on mutual exchange of energy and information between supply and demand sides, as expansion and integration of smart cities progress, there are various aspects in which diversity and complexity are influencing further development of smart cities. Smart cities consist of various types of hardware as well as software for efficient and resilient energy supply and applications, involving a large amount of different kinds of data. Actors and stakeholders are also diverse in the entire supply chain, including energy generators, distributors, technology developers, system operators, local communities, and consumers at the end. That implies that there exist various kinds of interests and concerns, such as energy efficiency, economic costs, environmental impacts, resilience to external shocks and disasters, accessibility and inclusiveness to end users, privacy, and cyber security.

Reflecting the diversity and complexity of smart cities, it would be possible to interpret the concept of smart cities and to create and implement innovation in various ways, depending on the local conditions and contexts. Semantic analysis of discourse on smart cities suggests that Japan has basically focused on improving sophistication of application technologies for extensive use of home appliances and electric vehicles, whereas the United States has paid attention to creating and maintaining security through improvement in resilience against physical as well as virtual threats. Network analysis of the key actors involved in smart city projects in Japan shows a relatively concentrated structure dominated by a small number of large actors, mainly government organizations and electric and electronic companies. In contrast, the US network reveals s distributed structure with many actors, such as utilities and smart meter manufacturers including SMEs and start-ups.

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, 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. 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. And 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 feed-in-tariff (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 more than capacities of 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 been 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.

Gradual shift from technological road-mapping to social system demonstration was also important in facilitating systemic approaches to innovation on smart cities. Iterative processes of revising the technological roadmap on PV were conducted by the funding agency NEDO. NEDO PV 2030 roadmap was initially published in 2004. Then the roadmap was replaced in 2009 by a revised one, NEDO PV 2030+ and subsequently by NEDO PV Challenges in 2014. In this process the main focus was placed on technological development. Then the support provided by NEDO 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 supported was provided for the development and demonstration of multiple, large-scale technologies coordinated for introducing renewable energy to the grid. And since then, demonstration of smart cities incorporating social needs has been encouraged with financial assistance.

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. They were mainly aimed at verifying emerging advanced technologies concerning smart cities, including cogeneration, renewable energy, energy storage, electric vehicles, and energy management systems (EMSs). At the same time these projects were also targeted at establishing robust business models with active participation of relevant stakeholders, including local communities and residents as well as technology provides 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 large-scale introduction of renewable energy and electric vehicles, with participation of 4,000 households equipped with HEMS, 10 large-scale building, and multiple storage batteries. In Toyota local production of energy for local consumption 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 intended to test 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, optmization 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 a significant effect of accelerating technological integration, reliability, and learning through trial and errors. 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 disadvantage under normal conditions. Through these demonstration projects, large-scale adoption and intensive learning became possible, inducing the prices of component technologies and the cost of operating energy systems to decline.

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 have initially slowed down the market to take off. Open Automated Demand Response (OpenADR) 2.0 technology standard was adopted, following feasibility, interoperability and connectivity testing in the summer of 2013. 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, as LED lights, smart thermostats, plug-in electric vehicles, rooftop solar, demand-flexible water heaters, battery energy storage, and other appliances are now integrated with the IT network. 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 used to be 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. Conclusion

Based on the analysis of the development of smart cities in Japan, we can identify several challenges in implementing system transformation. We need to have clear visions with regard to what kinds of smart cities we would like to establish and to match the visions with feasible plans for implementation. Strong leadership for projects and transparency in the process of decision making and implementation are also important. Under the existence of the significant degree of symmetry of knowledge and expertise between large technology companies on the one side and local government and communities on the other side, we also need to consider how it would be possible to secure serious and active participation of end users. Robust business models are currently missing, which has an effect of discouraging private companies to take over the demonstration projects that have been mainly 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. 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 on institutional landscape at the macro level and specific technologies at the micro level. That was particularly important for the creation and liberalization of energy markets in encouraging new entrants and entrepreneurship and consequent competition. Iterated processes of road-mapping of technological development to social system demonstration evolved 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.

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