Encouraging Innovation for Smart Cities: An Analysis of Innovation Systems and Implications for Public Policy

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Brief Self Introduction

- B.Eng. in Chemical Engineering, University of Tokyo
  - Three-Phase Fluidized Beds
- M.S. in Chemical Engineering, California Institute of Technology
  - Physical and Chemical Processes of Air Pollution
- Ph.D. in Economics and Policy Studies of Technical Change, MERIT-UNU/INTECH Program, University of Maastricht, The Netherlands
  - Effects of Environmental Regulation on Innovation
- Research Center for Advanced Science and Technology, University of Tokyo
  - University-Industry-Government Collaboration for Innovation
- National Institute of Science and Technology Policy (NISTEP), Japanese Ministry of Education, Culture, Sports, Science and Technology
  - Science, Technology and Innovation Policy
- Graduate Program in Sustainability Science and Graduate School of Public Policy, University of Tokyo
  - Public Policy, Corporate Strategy and Institutional Design for Promoting Innovation for Global Sustainability
- Department of Science, Technology, Engineering and Public Policy (STEaPP), University College London (UCL)
  - Mobilization of Science, Technology, and Engineering Knowledge in Public Decision Making on International Environmental Issues, including Air Pollution in East Asia
- School of Energy and Environment, City University of Hong Kong
  - Innovation on energy, environment, and sustainability, Smart Cities, IoT

In Collaboration with

- Martin Karlsson, EU Delegation to the Kyrgyz Republic, Bishkek, Kyrgyz Republic
- Gregory Trencher, Clark University, Worcester, MA, United States
- Roy Nyberg, Institute of Science, Innovation and Society, University of Oxford, United Kingdom
- Carlos López-Gómez, Centre for Science, Technology and Innovation Policy, University of Cambridge, United Kingdom
- Clarisse Pham, EU-Japan Centre for Industrial Cooperation, Tokyo, Japan; and Science Po, Paris, France
- Nobuyuki Sakai, Graduate School of Public Policy, University of Tokyo, Japan

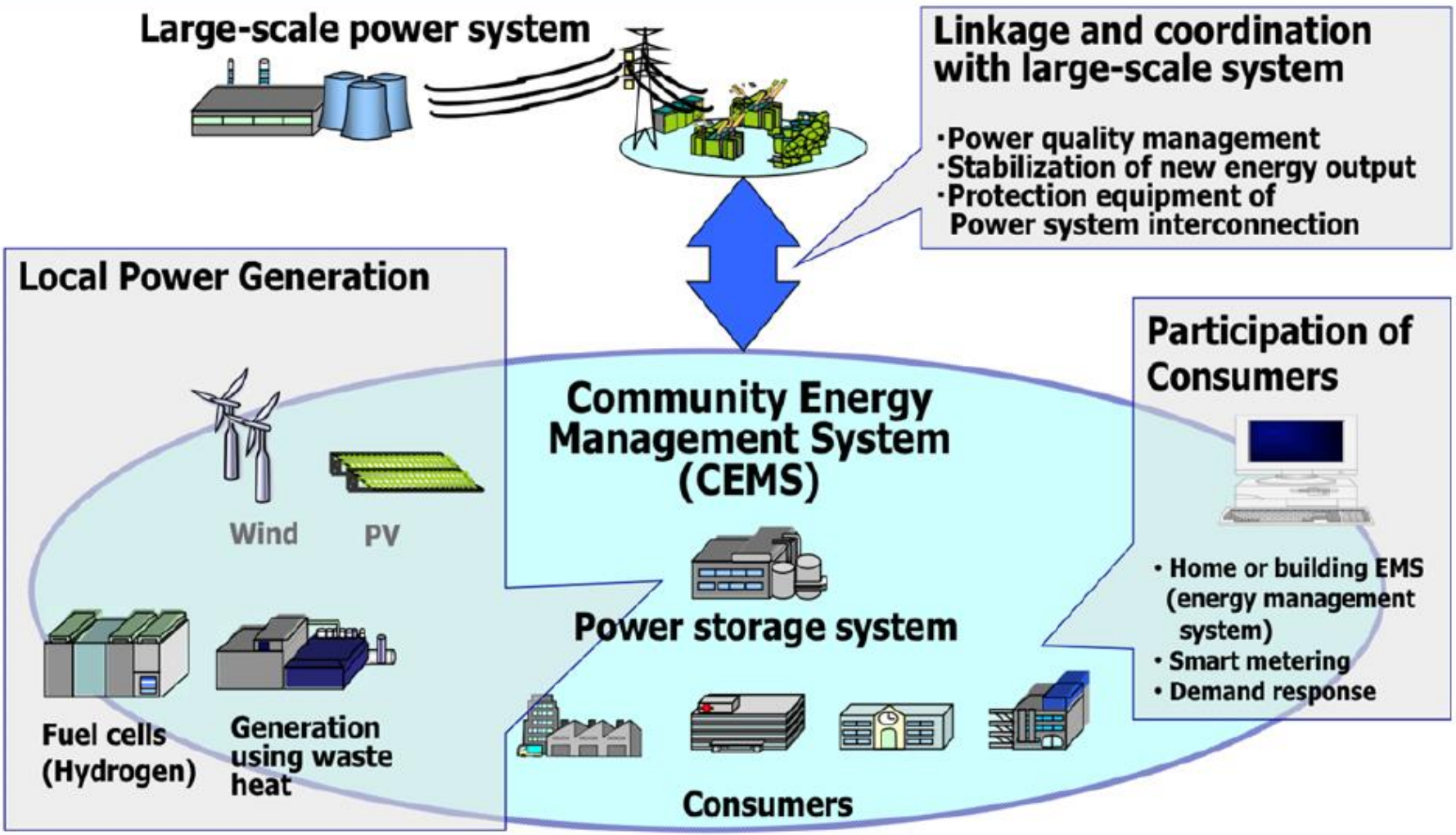
Backgrounds of Smart Cities

- Old and deteriorating infrastructure for energy distribution established long time ago
- Large-scale introduction of renewable energy influencing the quality of electricity with regard to voltage and frequency
- Cost pressure to improve energy efficiency and to cut back its consumption during peak periods
- Disasters, e.g., Fukushima accident, demonstrating the vulnerability of conventional centralized and rigid energy systems
- Emerging advanced technologies including ICTs and storage batteries, with cogeneration and renewable energy through distributed energy systems

Functions of Smart Cities

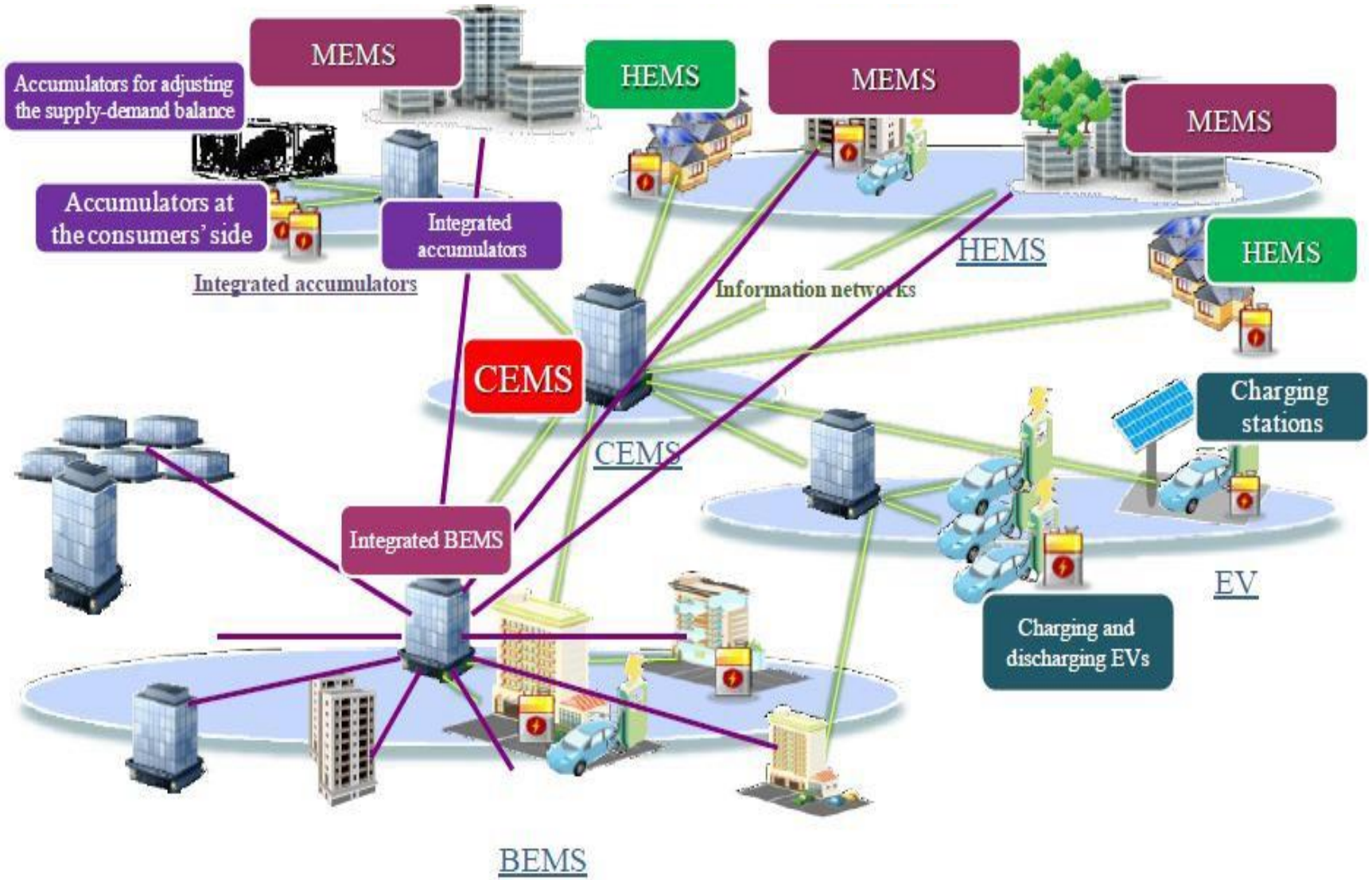
- Strengthening the resilience of energy supply against disruptions and disasters such as earthquakes, typhoons, and hurricanes through distributed energy systems
- Reducing environmental burdens including carbon dioxide emissions by increasing renewable energy sources and efficient energy usage
- Establishing efficient energy systems by utilizing 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
- Reducing capacities of thermal power generation prepared for peak energy consumption by establishing efficient electricity systems from a mid- to long-term perspective

Smart Cites based on Mutual Exchange of Energy and Information between Supply and Demand Sides



Source: Fuji Electric

Expansion and Integration of Smart Cities



Diversity in Implementing Innovation on Smart Cities

- Hardware as well as software, for efficient and resilient energy supply and applications involving a large amount of various kinds of data
- Actors and stakeholders, including energy generators, distributors, technology developers, system operator, local communities, consumers
- Interests and concerns, e.g., energy efficiency, economic costs, environmental impacts, resilience to external shocks and disasters, accessibility and inclusiveness to end users, privacy, cyber security
- Interpretation and understanding of the concept of smart cities, depending on local conditions and contexts

Research Objective

- Analyse the characteristics and processes innovation on smart cities in Japan and the US

Research Questions

- What are the knowledge and technological domains in implementing innovation?
- Who are the main actors in innovation efforts?
- What are the key drivers and obstacles in innovation?
- What are the influence of institutional environments including public policies and regulations?

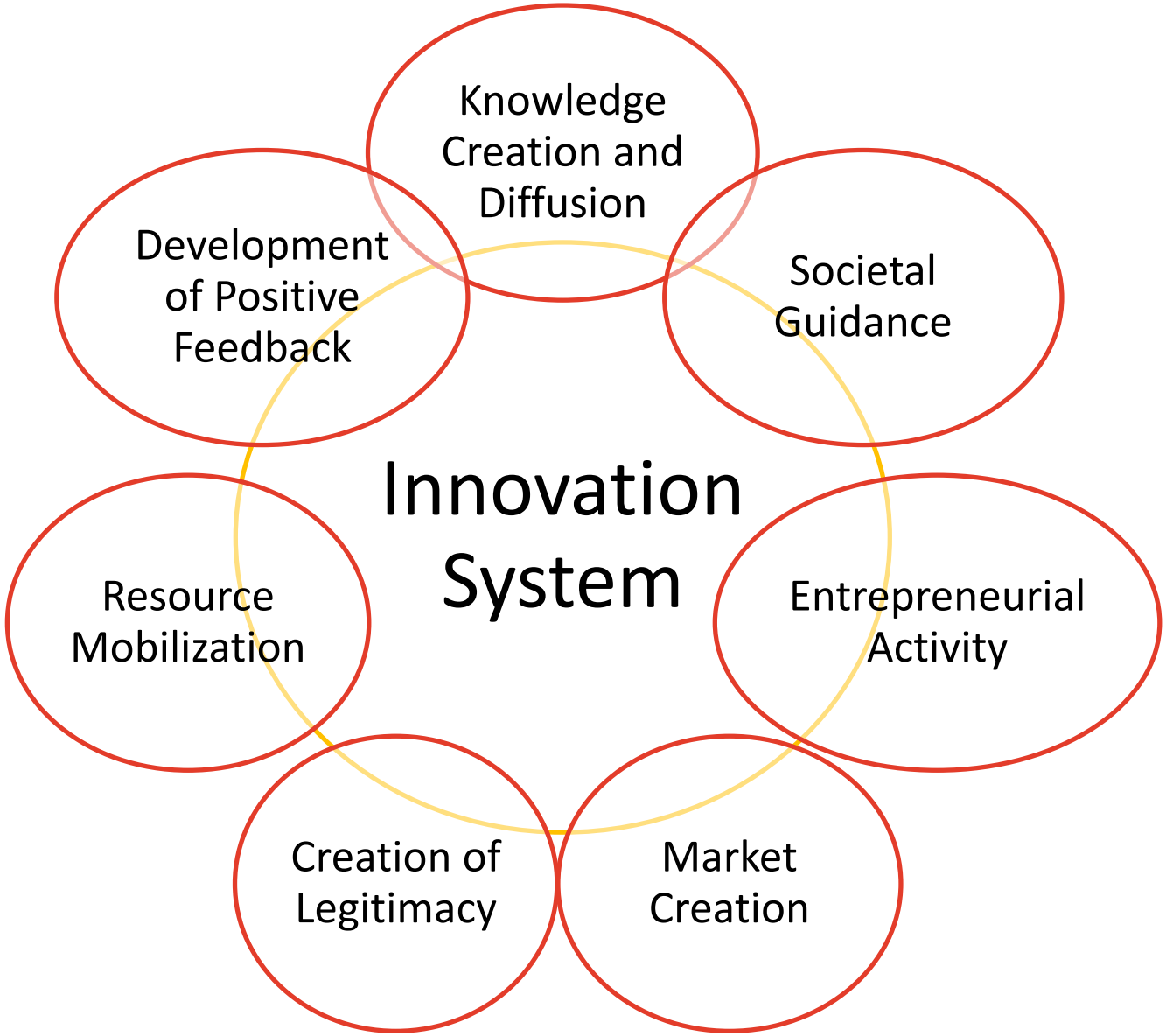
Innovation Systems

- Central Role of Research and Development (R&D) and Learning
- Traditionally three main actors:
  - University
  - Industry
  - Government

Components of Innovation Systems

- Knowledge
  - Specificities of knowledge and technological domains
- Actors
  - Heterogeneity, networks, interactions
- Institutions
  - Policies, regulations, standards, norms, established practices

Functions of Innovation Systems



Innovation as a Co-Evolutionary Process of Technological and Institutional Developments

- Knowledge at the base of innovative activities changes over time and affects the boundaries and structure of sectoral innovation systems.
- Actors and networks are highly affected by the characteristics of and changes in the knowledge base with significant differences across sectoral systems.
- 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.

Data Sources

- Collection of information through primary and secondary sources
  - books, articles, on-line conferences, industry fair visits
- Database on smart city projects (as of 2013)
- Semantic analysis
  - Abstracts (more than 300) from Web of Knowledge
  - Project documents
- Interviews
  - Academics, government officials, utility companies, electronics companies, business organizations, independent analysts (12-13 in Japan and U.S.)

Technological Domains

- Generation control, automation and power electronics
- Grid control software
- Grid sensing, automation and control technology
- Communication infrastructure
- Conductor technology and approaches
- Load control and advanced metering infrastructure
- Energy storage
- Electric vehicle charging infrastructure

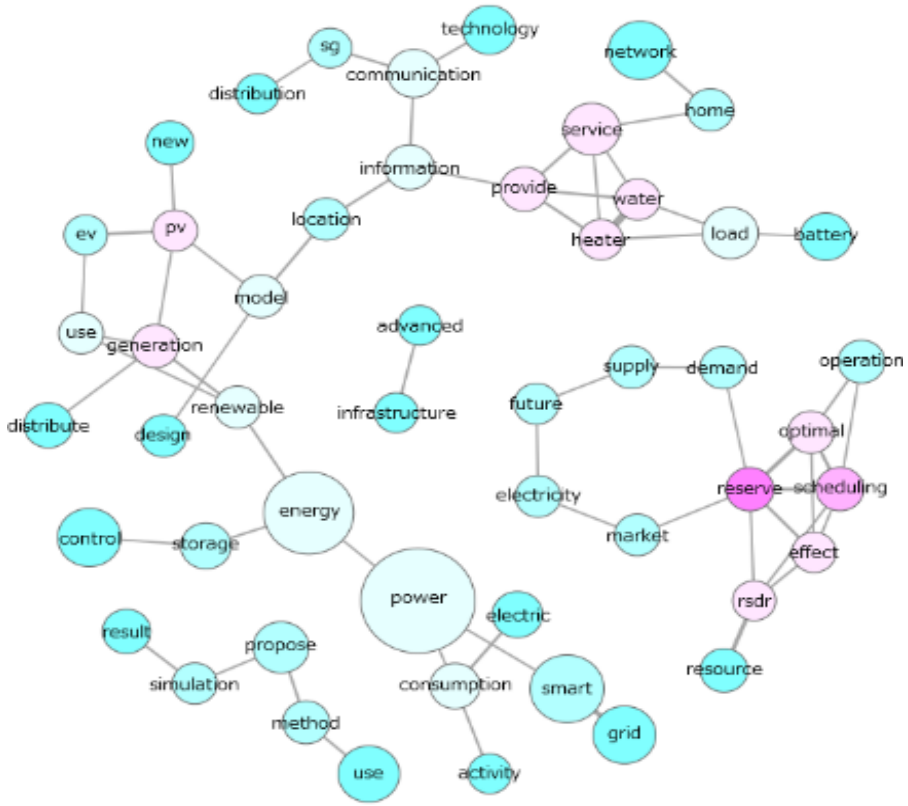
Generation

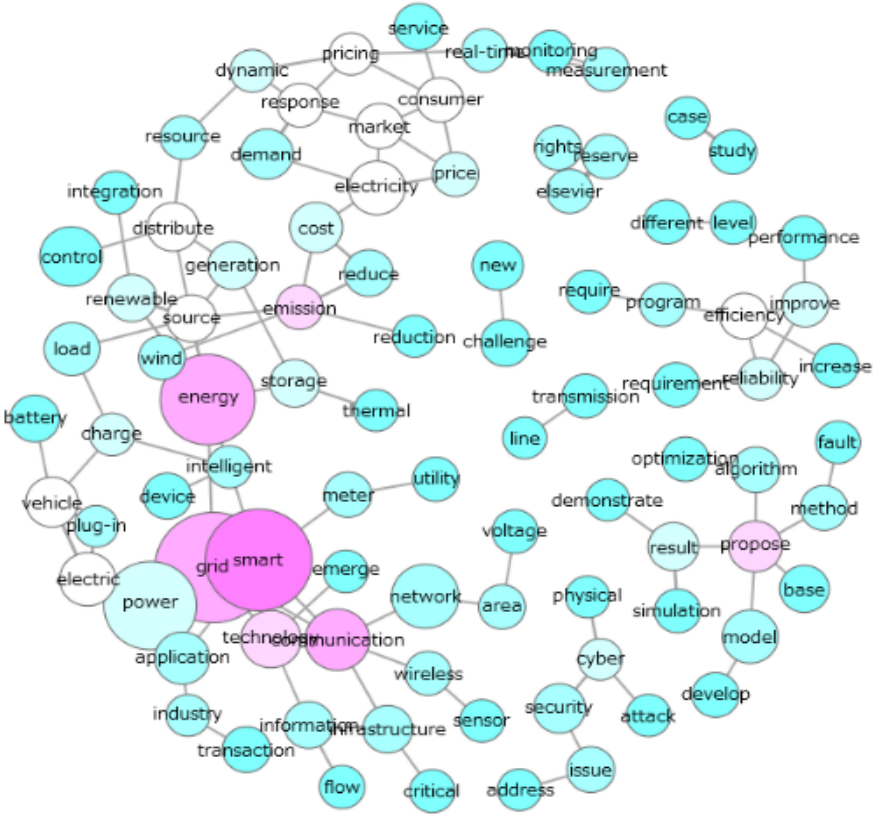
Transmission and distribution

Distribution and consumption

IEA (2010)

Knowledge and Technology Domains on Smart Cities in Academic Articles



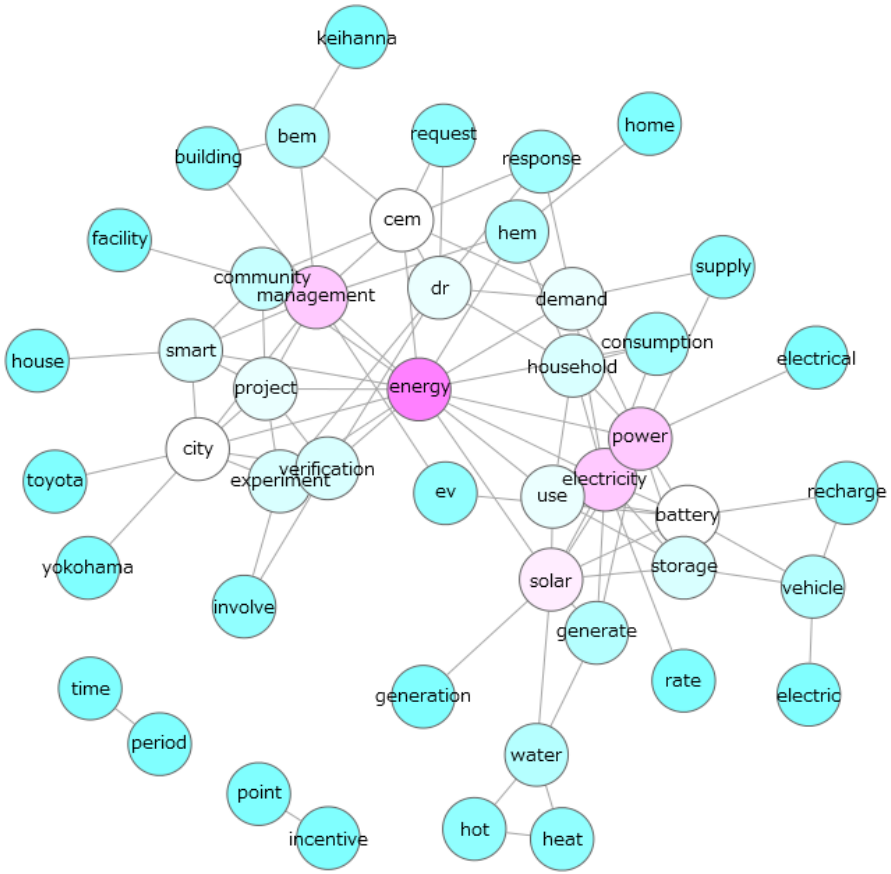


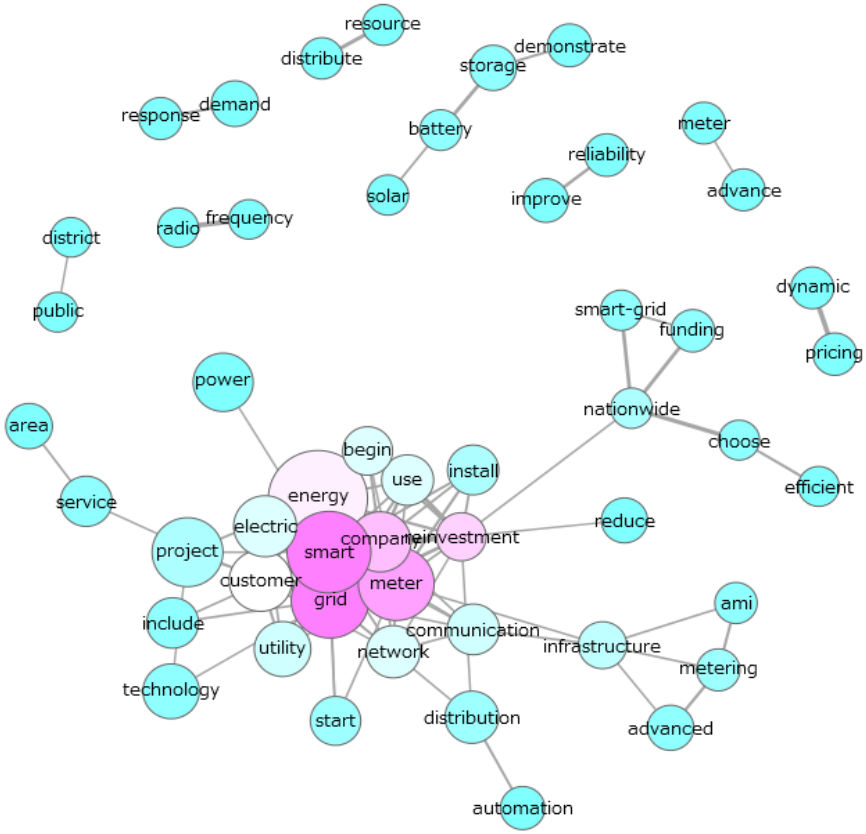
Japan: renewable energy, particularly PV, distributed energy, and energy storage

US: grid, smart meters, communication, infrastructure network

Yarime and Karlsson (2016)

Knowledge and Technology Domains on Smart Cities in Project Documents





Japan: application technologies for home appliances and electric vehicles, community management

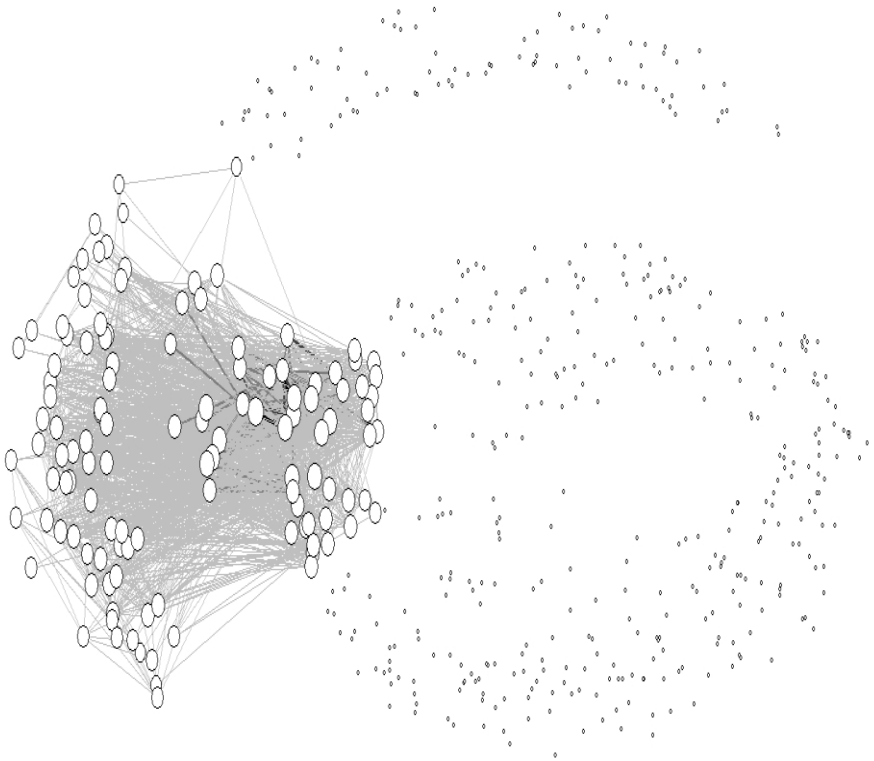
US: grid and smart meter technologies, cost reduction

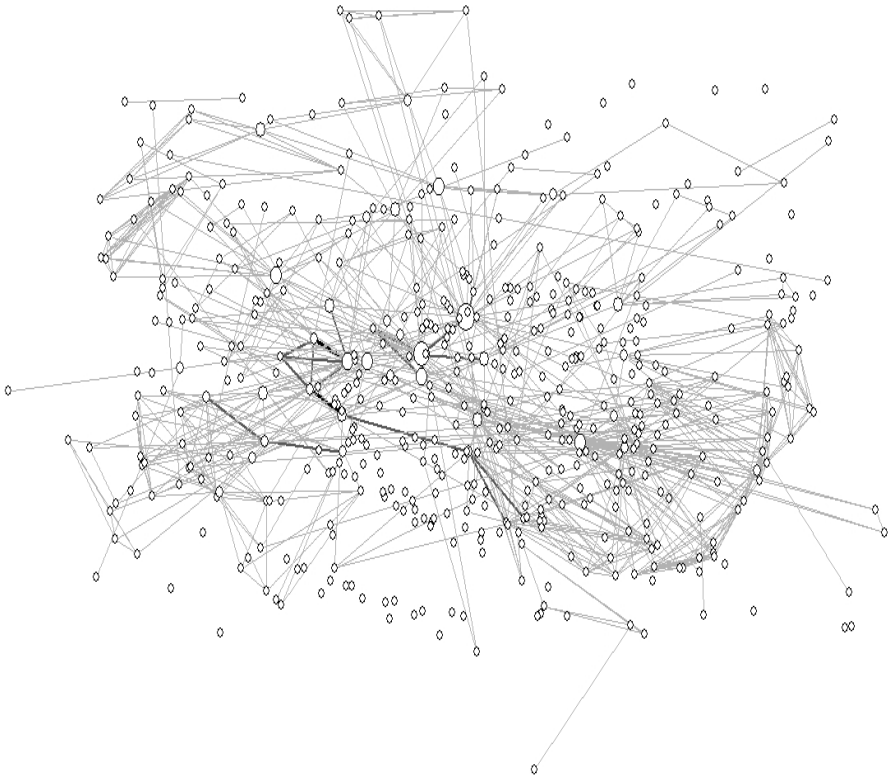
Yarime and Karlsson (2016)

Different Focuses on Knowledge and Technology Domains

- Japan
  - Focus on resilience to natural disasters and distributed renewable energy
  - Low importance of cost
  - Focus on non-grid functionalities
  - Broad, integrative
- US
  - Focus on resilience to attacks and cost reduction
  - Conservation and distributed generation less important
  - Focus on grid-automation
  - Low importance given to non-grid functionalities

Network of Actors Involved in Smart Cities





Japan: concentrated structure dominated by a small number of large actors, including government organizations and electric & electronic companies

US: distributed structure with many actors, such as utilities and smart meter manufacturers including SMEs and start-ups

Yarime and Karlsson (2016)

Major Actors in Japanese Network on Smart Cities

	Type	Degree	ARD	Eigenvector	Betweenness
Hitachi	Electronics company	74	303	0.173066	5212.703
TOSHIBA	Electronics company	64	298	0.165316	3735.588
Mitsubishi Corporation	Trading company	67	299.1667	0.171806	2908.344
NEDO	Governmental funding agency	28	265.3333	0.044392	2735.742
Sharp	Consumer electronics company	91	262.4989	0.243331	1603.521
Denso	Automotive component supplier	55	293	0.174657	1567.229
Fuji Electric	Infrastructure vendor	53	277.6672	0.141623	1516.667
JX Nippon Oil & Energy	Petroleum company	55	293.5	0.166895	1481.08
Panasonic	Electronics company	35	283.5	0.098062	1276.681
Furukawa Electric	Infrastructure vendor	47	272.5004	0.132096	1187.081
University of Tokyo	University	13	269.5	0.025997	1154.299
Sumitomo Electric Industries	Infrastructure vendor	55	293.5	0.160089	1123.101
Urban Renaissance Agency	Real estate agency	47	275.5005	0.123371	960.8317
TOTO	White ware vendor	30	278	0.101322	917.3737
IBM	Software vendor	30	278	0.101322	917.3737
Omron	Automotive component supplier	24	275	0.061349	770.785
Kansai Electric Power Co	Electric utility	24	275	0.061349	770.785
Iwatani	Gas equipment vendor	29	263.3333	0.098677	658.7583
Nittetsu Elex	Infrastructure vendor	29	263.3333	0.098677	658.7583
Tokyo Gas	Gas utility	31	281.5	0.089186	609.8406

Major Actors in US Network on Smart Cities

	Type	Degree	ARD	Eigenvector	Betweenness
EPRI	Research institute	28	194.8334	0.113018	7995.122
GE	Electronics company	29	199.6667	0.122854	7513.267
Sensus	Meter vendor	17	178.0835	0.048041	6957.279
Landis+Gyr	Meter vendor	17	186.2501	0.086227	3986.014
Southern California Edison	Electric Utility	16	181.8334	0.069304	3706.082
IBM	Software vendor	26	189.8333	0.133678	3650.072
Pacific Gas & Electric Company	Electric utility	15	143.1001	0.022026	3307.329
Premium Power	Infrastructure vendor	8	135.2502	0.013672	3255.385
Aclara	Infrastructure vendor	10	170.0001	0.049314	2633.994
Eaton	Infrastructure vendor	12	175.3334	0.065682	2546.157
PJM Interconnection	RTO	8	174.25	0.055321	2383.878
Itron	Meter vendor	10	177.25	0.062162	1970.951
Navigant	Consultancy firm	4	169.5833	0.051425	1970
Science Applications International	Infrastructure vendor	8	105.0667	0.001076	1970
Oncor	Electric utility	19	183.4167	0.12121	1877.981
DTE Energy	Electric utility	2	165.5	0.041463	1749.594
Cooper Power Systems	Infrastructure vendor	8	178.2501	0.07408	1740.068
American Electric Power	Electric utility	18	188.5001	0.134307	1677.09
S&C Electric	Infrastructure vendor	12	148.4667	0.038026	1660.706
Austin Energy	Electric utility	8	138.0169	0.020919	1580

Policies and Regulations Influencing the Innovation Systems of Smart Cities in Japan

- Economic incentives through feed-in-tariff to promote renewable energy
- Roadmapping on key component technologies
- Demonstration projects incorporating local conditions and contexts
- Platforms for strategic partnerships among stakeholders including academia, industry, government, and local communities
- Standard setting for smart meters and equipment
- Liberalization of energy markets at the system level

Feed-in-Tariff Program for Promoting Renewable Energy

- Shut-down of nuclear power plants following the Fukushima accident in March 2011, accelerating the expansion of renewable energy as a strategy to make up for lost power generation and to reduce Japan's dependence on imported energy
- Government goal announced in June 2011 of putting PV systems on 10m roofs by 2030
- FIT introduced in 2012 to encourage the installation of renewable energy, particularly solar PV
- Revised FIT for PV to account for more than 80% of newly installed capacity in the coming decade
- Over 80GW of solar power approved, but only 23GW installed by the end of 2014
- Installations slowed as utilities have denied additional grid access to new solar farms
- Current grid infrastructure not set up for the large-scale adoption of renewables such as solar and wind power, with further deployment disrupting the operations of the grid

Iterated Processes of Road-Mapping: From Technological Development to Societal Participation

- Revisions of the roadmap on PV through iterated consultations with experts in academia and industry
- 2004 New Energy Development Organization (NEDO) PV 2030
- 2009 NEDO PV 2030+
- 2014 NEDO PV Challenges
- Mainly focused on technological development
- Increasingly addressing societal concerns and expectations involving end users

Supporting Technological Development to Societal Demonstration and Experimentation

- Support provided through the funding agency New Energy Development Organization (NEDO)
- Prior to 2000: Development of individual technologies for introducing renewable energy to grid
- 2000-2010: Development and demonstration of multiple, large-scale technologies coordinated for introducing renewable energy to grid
- 2010 onwards: Demonstration of smart communities incorporating social needs

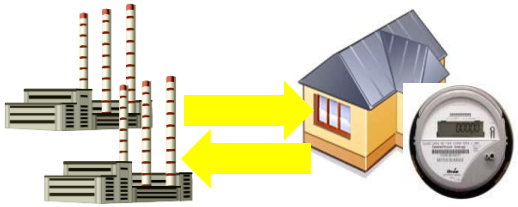
Demonstration of Smart Communities

- Demonstration of smart communities in Yokohama, Toyota, Keihanna, and Kitakyushu implemented in 2011-2014
- Aimed at verifying emerging advanced technologies concerning smart communities, including cogeneration, renewable energy, energy storage, electric vehicles, and energy management systems (EMSs)
- Also aimed at establishing robust business models with active participation of relevant stakeholders, including local communities and residents

Local Differentiation of Demonstration Projects (2011-2014)

Housing complex

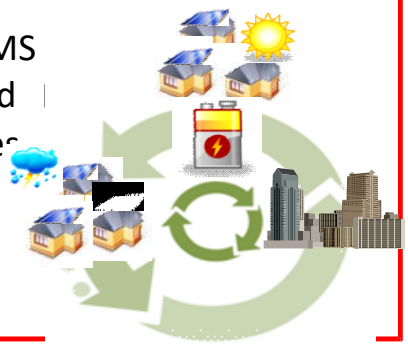
・700 households and HEMS
・Consulting business about saving energy.



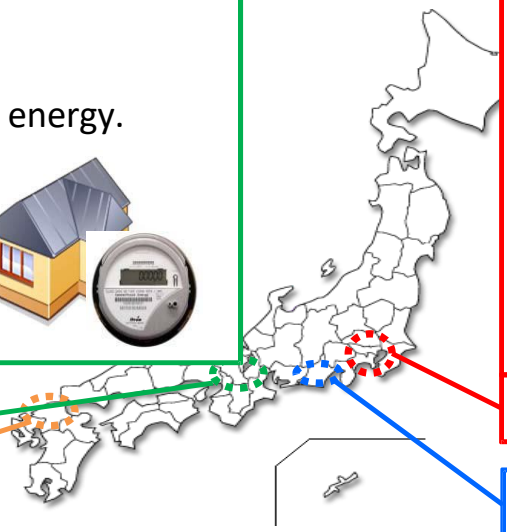
Keihanna Science City

Wide-area metropolis

・4000 households and HEMS
・10 large-scale building and
・Multiple storage batteri e



Yokohama City



Kitakyushu City

Designated supply area

- Power is supplied by Nippon Steel & Sumitomo Metal Corporation.
- Dynamic pricing system for 180 households.

Toyota City

Separate housing

・local production for local consumption
・67 households equipped with solar panels, household fuel cells , storage batteries.
・Advanced transportation system(EV, PHV)

METI (2015)

2

Local Differentiation of Demonstration Projects

- Yokohama: Major city
  - Large-scale introduction of renewable energy and electric vehicles
  - 4000 households and HEMS, 10 large-scale building, multiple storage batteries
- Toyota: Local city
  - local production for local consumption
  - 67 households equipped with solar panels, household fuel cells , storage batteries. advanced transportation system (EVs, PHVs)
- Keihanna: Science city
  - Visualization of energy for control and management
  - Housing complex with 700 households and HEMS, consulting business on saving energy
- Kitakyushu: Industrial area
  - Optimization of various sources of energy
  - Power supplied by large steel and metal companies, dynamic pricing system for 180 households

Facilitating Technological Integration, Reliability, and Learning through Demonstration

- Various types of technologies for smart communities to be connected and integrated, including facilities for renewable energy, energy storage batteries, and energy management systems.
- Difficult to show the economic advantages of emerging technologies over conventional energy systems, discouraging their deployment for smart communities
- Large-scale adoption and intensive learning for the prices of component technologies and the cost of operating energy systems to decline

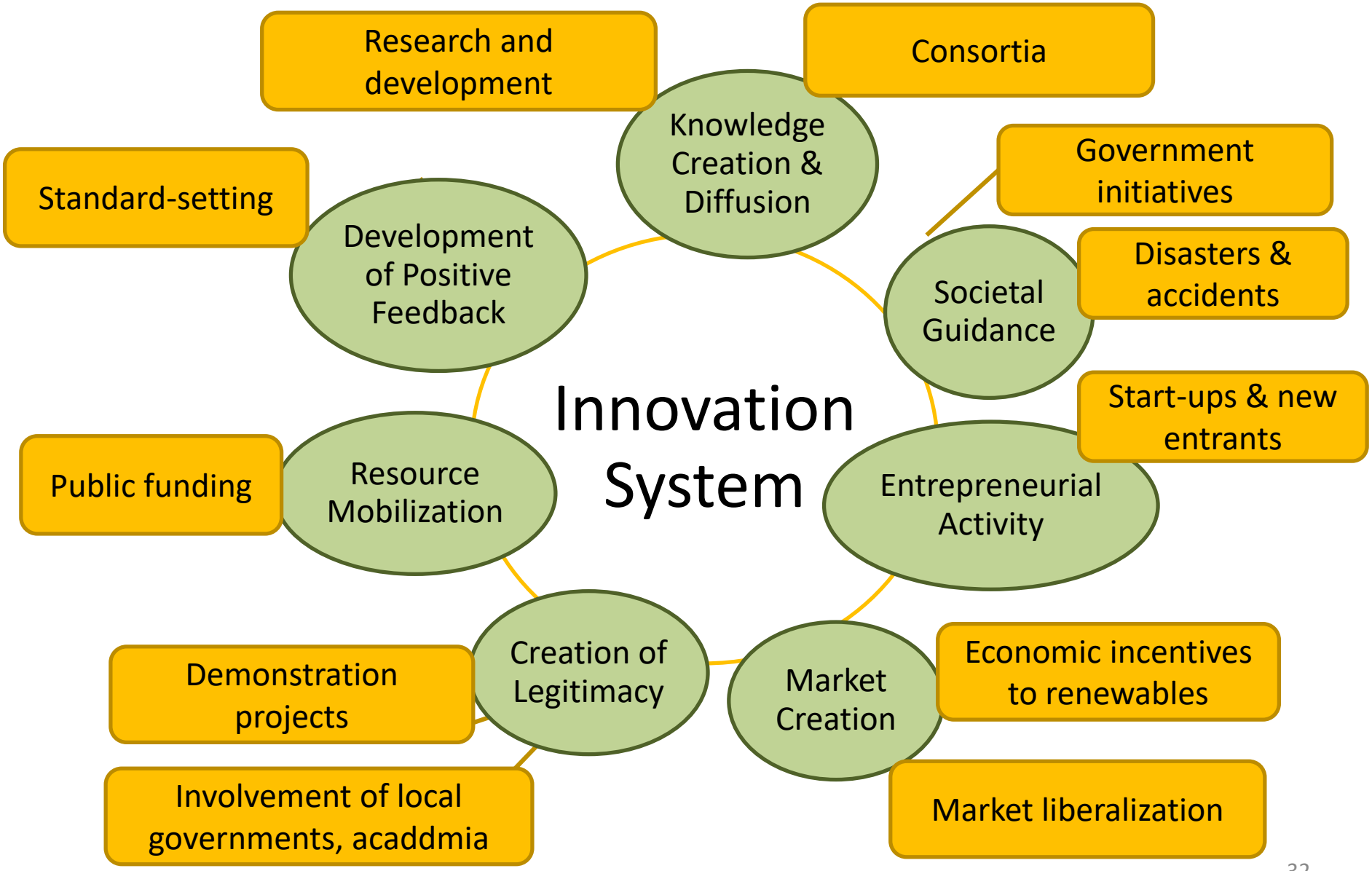
Standard-Setting for Smart Meters and Equipment

- Proprietary standards among competing providers having slowed down the market to take off
- Open Automated Demand Response (OpenADR) 2.0 technology standard adopted following feasibility, interoperability and connectivity testing in the summer of 2013
- With an application programming interface (API), the efficient development of applications facilitated, including HEMS and BEMS.
- Adoption of HEMS 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 integrate with the IT network, with HEMS Alliance formed by leading companies to prepare a multi-vendor device environment
- Various standards emerging rapidly for the Internet of Things (IoT) (e.g., ZigBee, Bluetooth Low Energy), leading to a need to consider coordination

Liberalization of Energy Markets

- Regional Monopoly System (until the 2000s)
  - Lack of systems to transmit electricity beyond regions
  - Few alternatives on tariffs, particularly in residential customers
  - Limited capacities in accommodating changes in the energy mix, including renewables
- Amended Electricity Business Act (November 2013)
  - Establishment of the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) in 2015 to promote wide-area electrical grid operation
  - Liberalization of the retail sale of electricity in 2016
  - Separation of power generation and power transmission in 2018-2020
- Strategic Energy Plan (April 2014)
  - Accelerated introduction of renewable energy (53GW for PV, 10GW for wind by 2030)
  - Emphasis on R&D and demonstration of transmission and distribution equipment
  - Establishment of regional/interregional grid for renewables

Functions of Innovation Systems of Smart Cities



Challenges in Implementing Innovation on Smart Cities

- Clear visions and matching with implementation
- Strong leadership and transparency
- Coordination among various standards in different fields and sectors
- Serious and active participation of end users
- Asymmetry of knowledge and expertise between large companies and local government and communities
- Robust business models
- Taking over the demonstration projects initiated with public funding by private actors
- Human resources with skills and capacities to understand and integrate technical and social dimensions