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Integrated energy-environment-public health-economy assessment of the LowEmission Development Strategies (LEDS) in the major urban areas in Japan

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1. Objectives of research program

Japan's energy industry faces a wide range of challenges, including the reliance on imports of fossil fuels through the immediate nuclear power phase-out and further focusing on reducing and decarbonizing its energy system. Initiatives are underway to decentralize the power sector in Japan from the centralized fossil-based systems to the distributed ones. Implementation of the Low Emission Development Strategies (LEDS) can enable the decentralization of the electric power sector in Japan. This research project was conducted in continuation of our previous funded research projects (JSPS Grant-in-Aid for Scientific Research (C) General (16K00650) and (Asia-Pacific Network under Collaborative Regional Research Program) and to develop and demonstrate a new strategic planning mechanism for achieving multiple benefits of LEDS in the selected cities in Japan, together with a robust analytical framework that can be used to assess those benefits during the development and implementation process. To this aim, the specific target was set to design and develop an analytical approach which helps policymakers and relevant stakeholders to determine opportunities for LEDS and also to address the main appropriate policy instruments available, based on the analysis of the practical experience with LEDS and related processes to date in the selected cities in Japan with more than one million inhabitants. In the first phase of the research, activities focused on evaluating the existing LEDS and clean energy policy developments, countermeasures, and challenges in selected cities. In the second phase, activities concentrated on designing strategic plans that achieve more significant benefits in selected cities.

2. Contents of the research

1) Robust quantitative modeling approach: In this investigation, to be able to quantify the multiple benefits (energy, environment, health, and economy), the concept of LCS (Low-Carbon Society) has been used. To this aim, a city-level CGE (computable general equilibrium) model has been developed based on the general equilibrium theory [1]. The CGE model includes two main parts: supply and demand. On the supply side, the microeconomic principles have been utilized to develop a concept that would represent the behavior of an urban energy system in a market with perfect competition. The local government, as a decision-maker in this market, strives for maximum satisfaction (or utility) of delivering

certain energy service to the end-users, such as providing required electricity at the end-user level. On the demand side, a spreadsheet simulation model based on the bottom-up end-user method and the Avoid-Shift-Improve (A-S-I) approach has been applied to the end-user levels in order to assess the effect of different scenarios of socioeconomic, technological, and demographic developments on energy consumption and emissions of the citywide energy system in a multi-sectoral context. Evaluating the public health benefits of clean energy development in the selected cities was based on the concentration-response (C-R) functions of the health effects include premature mortality and exacerbation of health conditions such as asthma, respiratory disease, and heart disease, which were collected from epidemiological research. The C-R functions have been used to link the estimated changes in concentrations to several health endpoints. The C-R functions were used to connect the expected changes in concentrations to several health endpoints by introducing the impact function of health effects.

2)Data gathering: Required detailed data were collected from the local energy office and academic organizations in selected cities. We organized several collaboration trips to the selected cities to visit our research collaborators and related stakeholders to obtain insight into specific proposed LEDS, including scale, challenges, and plans in their cities, and to ensure common understanding and consensus by all parties involved. The baseline scenarios were developed based on a comprehensive survey on the metropolitan environmental master plans, cap, and trade programs and climate change strategies to evaluate the existing LEDS and clean energy policy developments in each city.

3)Benchmarking: To reflect the results obtained from the quantitative analysis and in order to measure the socioeconomic and environmental impacts of the planned LEDS and monitor the success of sustainability interventions in the selected cities in Japan, we have developed a composite index that consists of a unique set of 4 dimensions (energy and climate, City planning, social welfare, and economic), so-called " Urban Sustainable Development Index (USDI). This index benchmarks the selected cities based on 13 indicators related to energy and climate, city planning, local economy, and social welfare. Energy and climate-related indicators include GHG emissions, air pollution (NOx, PM10, and PM2.5) and final energy consumption. City planning indicators include clean water accessibility, public transport development, waste collection and management, and urban green space area. The Local economy and social welfare progress are assessed by measuring the local GDP, labor productivity, unemployment rate, life expectancy, public health, and education. The values of the indicators are aggregated based on the Min-Max method for a final ranking. Among selected cities, Tokyo performs reasonably well in USDI with an almost equal share of different indicators, indicating that Tokyo Metropolitan Government developed and successfully implemented a number of policies and subprograms including the Tokyo Metropolitan Environmental Security Ordinance, the Tokyo Climate Change Strategy, and finally the Tokyo Metropolitan Environmental Master Plan that collectively aimed at reducing the energy-related GHG emissions of urban facilities.

In addition to the reduction of GHG emissions and the consumption of energy, these policies set a target to increase the ratio of renewable energy consumption to about 20% by 2030. The strategies that are incorporated within these policies, such as mandatory emission reductions, stakeholder interaction, and predefined emission targets should be considered as the most effective in terms of alleviating environmental pollution within the boundaries of an urban environment. The aggregated USDI scores for the top three megacities of Tokyo, Yokohama, Osaka, were estimated at 0.93, 0.85, 0.84, respectively. Detailed information can be found here=> http://farzaneh-lab.kyushu-u.ac.jp/USDI/USDI.html#/

4)Case study analysis: In addition to evaluating the existing LEDS, we examined the following low emission scenarios:

- *Yokohama)* Smart City Project as the next-generation energy infrastructure, which enables the large-scale introduction of renewable energy and smart-grid application to reduce CO2 emissions in this city. The results revealed that, emissions mitigation through implementation of this scenario accounted for 21% of GHG emission and 25.4% of total air pollutions by promoting the city's energy performance in both the electricity supply system and the end-user level [2].
- *Fukushima)* Implementation of an innovative hydrogen-based Hybrid Renewable Energy System (HRES), which can be used to provide electricity, heat, hydrogen, and water to the small community (80 households around power station in Shinchi-machi) in this prefecture. The HRES introduced in this scenario was based on the integration of solar power generation, hydrogen generation from Supercritical Water Gasification (SCWG) of wet biomass feedstock, hydrogen generation from solar water electrolysis, and a fuel cell to convert hydrogen to electricity and heat. As indicated by results, the proposed HRES can generate about 47.3 MWh of electricity and about 2.6 tons of hydrogen per annum, using the annual wet biomass consumption of 98 tons, with a Levelized Cost of Energy (electricity and heat) of the system at 0.38 $/kWh [3]. The implementation of the proposed HRES in the selected residential area has GHG emissions reduction potential of about 21 tons of CO2-eq per year.
- *Fukuoka)* Implementation of the stand-alone microgrid system that can be used in order to meet the electrical load requirement in a Japnese standard building in Kasuga City. The proposed system consisted of the solar PV (2.65 kW), wind power (2.01 kW) battery (14.86 kW), diesel generator (3.6 kW), converter (2.8 kW). The total cost of the proposed system was estimated at USD 42,300. The LCOE of the proposed system was estimated at 0.88 $/ kWh [4].
- *Osaka):* Implementation of a Hybrid Renewable Energy System (HRES) consists of a combination of the solar PV, wind turbine, fuel cell, electrolyzer, hydrogen tank, battery, and biomass generator to satisfy the electricity demand of a target residential region in Osaka with average daily electricity consumption of 4300 kWh As indicated by results, the grid-tied HRES can generate about 49% of the total electricity demand in the target residential area, with a Levelized Cost of Energy (LCOE) of the system at 0.36 $/ kWh.

3．Publication of research results

Books:

[1] Farzaneh, H. (2019). Energy systems modeling: Principles and applications. ISBN: 978-981-13-6220-0, Springer.

[2] Farzaneh, H. (2018). Devising a clean energy strategy for Asian cities. ISBN: 978-981-13-0781-2, Springer.

Peer-review Jurnal papers:

[3] Farzaneh, H. (2019). Design of a hybrid renewable energy system based on supercritical water gasification of biomass for off-grid power supply in Fukushima. Energies, 12(14), 2708

[4] Yoshida, Y., Farzaneh, H. (2020). Optimal design of a stand-alone residential hybrid Microgrid system for enhancing renewable energy deployment in Japan. Energies, 13(7), 1737.

[5] Farzaneh, H., De Oliveira, J. A., McLellan, B., & Ohgaki, H. (2019). Towards a low emission transport system: Evaluating the public health and environmental benefits. Energies, 12(19), 3747