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Energy Management Simulation for a Local Energy Supply System#

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ABSTRACT

The introduction and expansion of locally produced and consumed energy systems by local governments and other entities are garnering considerable attention. This study evaluated a local energy supply project in Shinchi, Fukushima Prefecture, Japan. We specifically focused on a cogeneration-based local energy supply system and conducted a simulation to assess the CO_2 reduction impact of expanding the supply area, increasing renewable energy integration, and implementing energy management technologies such as electric vehicle (EV) utilization, storage battery control, and demand response.

Keywords: Local energy management, Decarbonized town development, Energy simulation, Renewable energy, Demand response

NOMENCLATURE

Abbreviations	
EV	Electric Vehicle
DR	Demand Response
BaU case	Business as Usual case
R+E case	Introduction of Renewable energy + EVs case
SC case	Introduction of Smart Control case

1. INTRODUCTION

Reducing CO_2 emissions from fossil fuels, which constitute the majority of the greenhouse gas emissions in Japan, is crucial for achieving a decarbonized society [1]. Research on energy conservation has been conducted at various scales [2-4]. However, recent years have seen significant changes. While energy-saving measures played a critical role in the Kyoto Protocol [5], they have limitations in achieving long-term, large-scale reduction targets. Consequently, expanding the use of renewable energy sources, such as photovoltaics and wind power, has become increasingly important [6-8]. Local production and consumption of energy using renewable resources not only significantly impact CO_2 reduction but also reduce reliance on external energy sources and promote job creation, benefiting the local economy. Moreover, the increased frequency of natural disasters has heightened the need for distributed energy systems and local energy production to enhance resilience and ensure energy availability during emergencies. In response, implementing and scaling up energy systems led by local entities, such as local governments, has become an urgent priority [9]. Achieving these goals requires more than individual technological advancements.

Therefore, we have established demonstration sites, such as disaster recovery areas, and developed methods for efficient use of local resources, stakeholder engagement, and support for local government decision-making. As part of this collaborative effort, we conducted evaluation research on local energy supply systems in Shinchi, Fukushima Prefecture, to expand these methods to other regions [10]. We plan to continue technological development and move towards social implementation.

We aimed to horizontally deploy the results of previous research across various local areas. The goal of this research is to facilitate local production and consumption of energy through the future implementation of energy systems. To achieve this, the project is part of a research and development effort focused on identifying the conditions necessary for establishing local energy projects, considering resident acceptability and local economic impacts, and linking these findings to social implementation through collaboration with local stakeholders.

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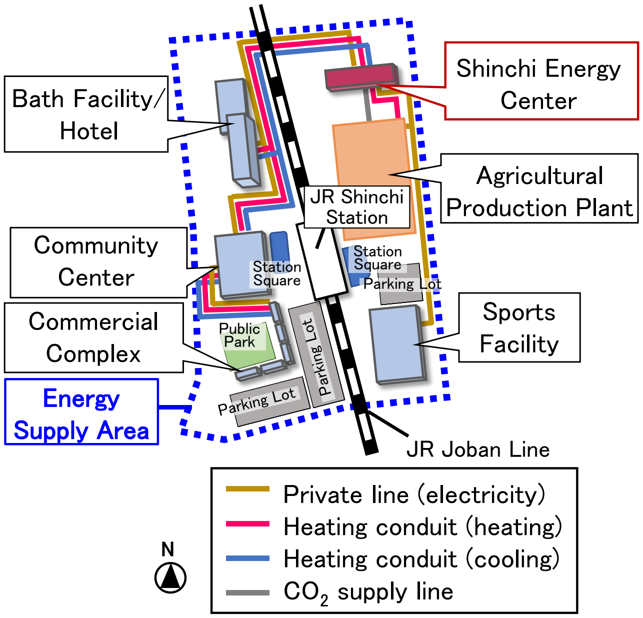

Fig. 1 Current energy supply area

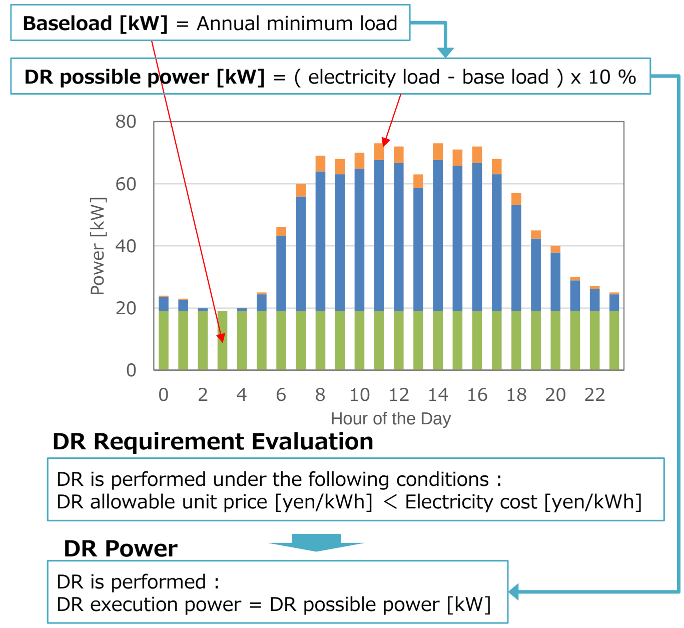

Fig. 2 Illustration of economic DR

2. CURRENT ENERGY SUPPLY IN THE TARGET AREA

Following the Great East Japan Earthquake, Shinchi proposed a concept aimed at revitalising the local area by enhancing environmental, economic, and social values and integrating the vitality of the local community with information and communication technologies. In March 2013, the National Institute for Environmental Studies formalised a collaboration agreement with Shinchi, engaging in academic cooperation to achieve this vision. As part of its core reconstruction project, the town introduced a cogeneration-based local energy supply system to promote the development of smart communities in the area (Fig. 1), which had been severely damaged by the tsunami [11]. A local energy supply company was established in February 2018, and the Shinchi Energy Center, which provides electricity and heat to various facilities around Shinchi Station, was completed in November 2018. The Shinchi Energy Center uses distributed power sources and heat source systems, including cogeneration systems powered by natural gas, to supply electricity and heat. These are distributed to facilities within the local area via private lines and heat-supply conduits. The supply area targets hotels and hot spring facilities, which have high heat demands for commercial use, and aims to effectively utilise hot water waste from cogeneration. Additionally, an exhaust heat input-type absorption chiller/heater (GeneLink) has been introduced, which uses exhaust heat from gas engine cogeneration to produce cold and hot water, thus enabling the use of exhaust heat for summer air conditioning. The Shinchi Energy Center operates as a locally distributed smart grid, capable of disconnecting from the main grid temporarily to ensure a constant power supply for disaster prevention in the event of a large-scale outage. We have been researching methods to improve the efficiency of energy supply and demand in local energy projects and to expand these projects to other areas [12, 13].

3. ENERGY SIMULATION METHOD

The simulation procedure is as follows: First, the floor area of the hypothetical building for each application was set as the condition for the target area, and case studies for the technologies to be introduced were established. These conditions were then used to estimate energy demand and assess the effects of the local energy supply system and the renewable energy to be introduced.

The amount of photovoltaic power generated was calculated based on solar radiation and external air temperature at a given time. Similarly, wind power generation was calculated from the wind speed at that moment. The total power generated by renewable energy sources was determined using these calculations.

Next, the smart power control options were examined and calculated. The main energy management measures included:

Economic demand response (DR) is implemented for local Power Producers and Suppliers (PPS) when the cost of operating the power supply or load control in the region is lower than the wholesale electricity unit price (Fig. 2).

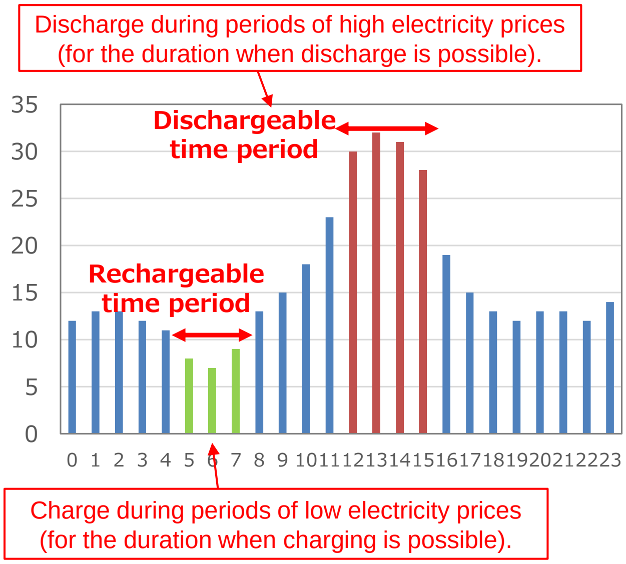

Fig. 3 Illustration of DR for storage batteries and EVs

For facilities with storage batteries, discharging occurs when electricity prices are high, and recharging happens when prices are low (Fig. 3). The available capacity within the upper and lower limits of the remaining charge is used to set electricity charges for up to 24 hours in advance, according to the unit price that aligns with the available capacity, starting from the highest timeframe. Charging is carried out if the current time matches this timeframe while discharging occurs if the timeframe with a unit price that meets the usable capacity corresponds to the current time.

When the total power demand on the self-employed line exceeds the contracted power, the equipment with the lowest operating unit price is used to avoid surpassing the contracted power limit (Fig. 4). If the power generated by renewable energy on a self-employed line exceeds the power load and results in reverse power flow, the equipment with the lowest operating unit price is employed to increase the power load. This may include charging power storage equipment and stopping the cogeneration system (CGS) to prioritize electric heat sources.

The simulation in this study includes various additional energy management measures, but details are omitted here. Based on the results, the impacts of implementing locally optimal energy systems were evaluated.

4. ENERGY SIMULATION RESULTS

We evaluated a scenario in which the supply area was expanded, as illustrated in Fig. 5. The scenarios assessed under this evaluation included the following conditions: conventional equipment, distributed local

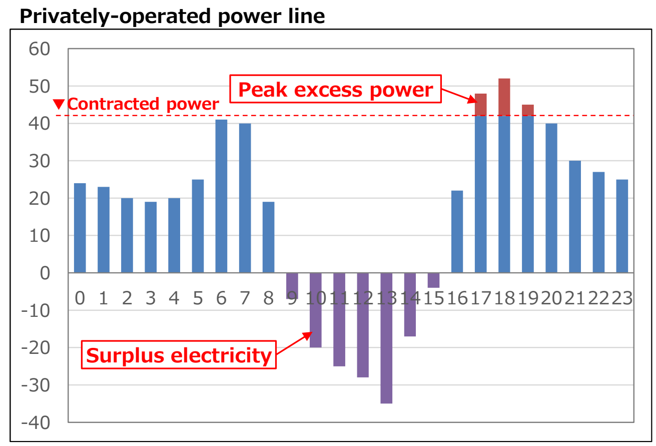

Fig. 4 Illustration of peak cut and surplus absorption for privately operated lines

energy supply, introduction of renewable energy, and electricity retail businesses (local PPS), incorporation of EVs, and optimal control of storage batteries.

Business as Usual (BaU case): Conventional equipment configuration and energy use. Cooling demand in each facility is met by electric heat sources (e.g., building multi-air conditioning systems), while heating demand is met by gas heat sources (e.g., gas boilers). Electricity is purchased from general electricity retailers, and all shared and personal vehicles in the area are gasoline-powered.

Introduction of Renewable Energy + EVs (R+E case): In this scenario, renewable energy sources such as solar and wind power are introduced, and vehicles within the area are converted to electric vehicles. The renewable energy generated locally is sold to general electricity transmission and distribution companies (electricity is not sold under the Feed-In Tariff (FIT) scheme, as it is subject to subsidies).

Smart Control (SC case): Building on the R+E case, air conditioning for facilities around the station is supplied by the energy center, with electricity provided through privately operated lines. A local PPS is established to transmit and supply electricity procured from the wholesale market and generated from local renewable sources to areas outside the privately operated lines' range. Additionally, stationary storage batteries are introduced within the privately operated lines, and various controls, such as prioritizing heat sources at the energy center, managing charging and discharging of EVs, and implementing demand response measures at each

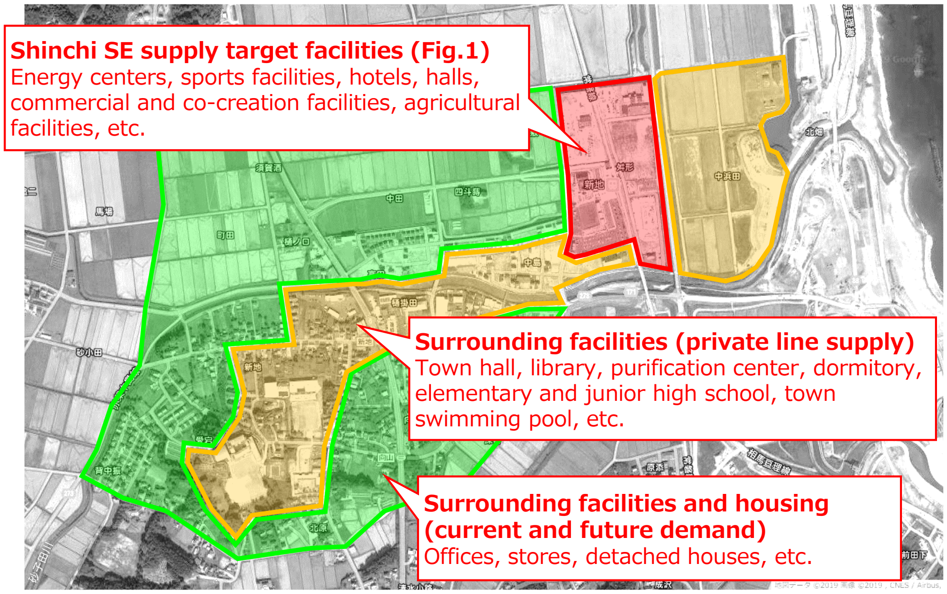

Fig. 5 Calculation area of this study

facility, are used to reduce peak demand within the privately operated lines. This scenario also addresses the self-consumption of renewable energy and demand response across the entire area.

The calculation results are shown in Fig. 6. Comparing the R+E and BaU cases, the introduction of renewable energy and the transition to EVs reduced annual CO_2 emissions by approximately 34% and annual energy costs by approximately 30%. These reductions are primarily due to the introduction of renewable energy sources. Furthermore, in comparison to the SC case, the implementation of energy management reduced annual CO_2 emissions by approximately 38%, attributable to the effects of the CGS and the high efficiency of the energy center. Additionally, annual energy costs decreased by approximately 42%, mainly due to lower electricity-metered charges and reduced basic charges resulting from the local PPS. However, studies on the effects of DR remain limited. When comparing renewable energy power generation, the sum of "self-consumption" and "surplus electricity sales" represents the total renewable energy generation. Since the amount of renewable energy equipment remains largely unchanged between the R+E and SC cases, there is no significant difference in total generation. In the SC case, surplus electricity is absorbed through the control of EVs and storage batteries, promoting local production and consumption, leading to an increase in self-consumption and a decrease in surplus electricity sold. Under the conditions of this study, the self-consumption rate of renewable energy increased by approximately 5%.

Fig. 6 illustrates that the reduction effect increased as more advanced conditions were applied. Among the scenarios examined, the introduction of renewable energy had the most significant impact on reducing emissions. However, the actual reduction effect naturally depends on the assumed scale of introduction; therefore, these results should be viewed as an example. To obtain more generalizable results, future studies should increase the number of evaluation cases based on various scenarios.

5. CONCLUSIONS

In this study, we extended the findings from local energy planning and evaluation research conducted by local governments in Shinchi Town, Fukushima Prefecture, and developed a general-purpose energy management simulation method to support the horizontal deployment of such systems in surrounding areas. This simulation method considers the climatic conditions of the target area, building applications and floor area, the technologies to be introduced, and other relevant factors. It examines various power control strategies, such as demand response, charging and discharging of storage batteries, and local power interchanges, and calculates the effects of introducing these systems. The results allow for the proposal of an optimal system for the introduction of a local energy system, facilitating the evaluation of its energy

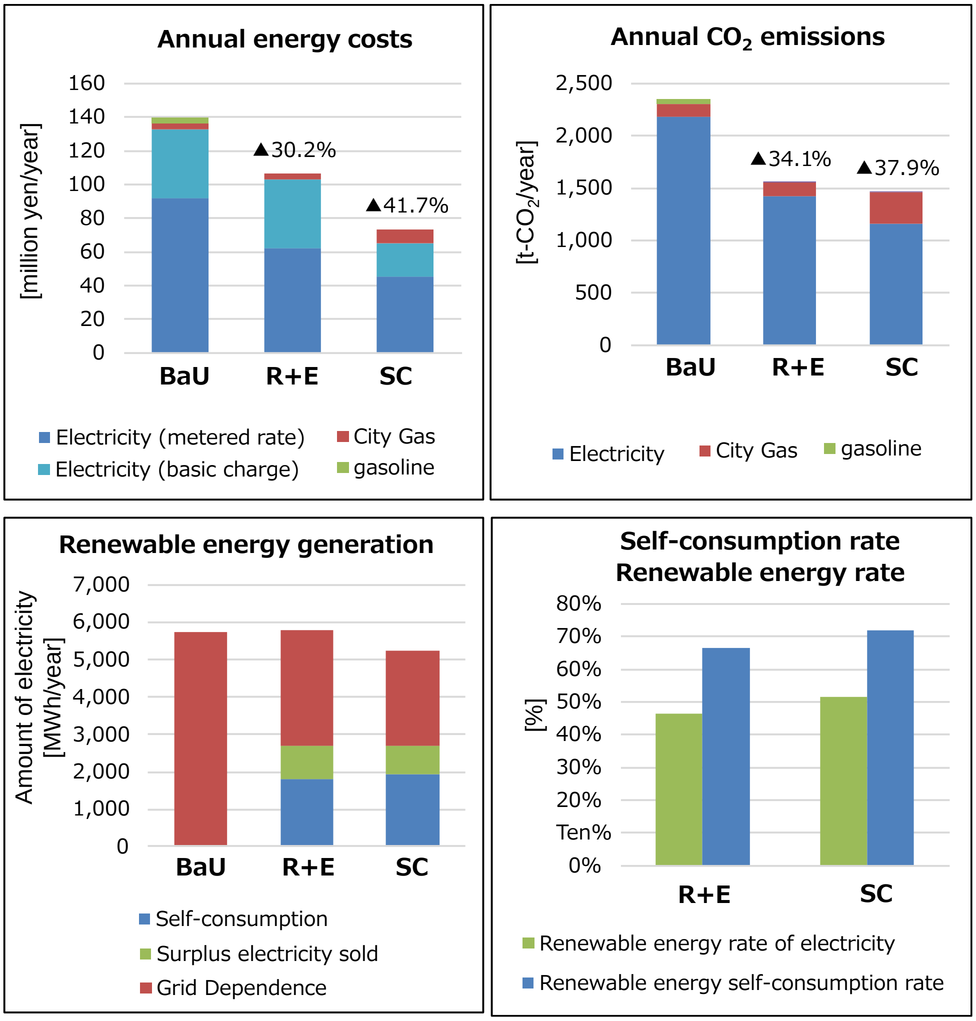

Fig. 6 Summary of calculation results

conservation, environmental performance, and economic impacts.

We simulated the effect of CO_2 emissions reduction by assuming the expansion of the local energy supply area and the introduction of various technologies in Shinchi Town. This simulation is particularly unique in linking temporal changes in renewable energy with corresponding changes in energy demand, and in evaluating scenarios where EV charging, discharging, and storage battery control are used to balance supply and demand. However, the actual reduction effect will naturally depend on the amount of renewable energy introduced. Therefore, increasing the number of evaluation cases is essential to obtain generalizable knowledge.

The energy management simulation method proposed in this study is being developed as a general-purpose tool. From an academic perspective, it can support plans to achieve efficient local energy management and the local production and consumption of energy in various regions with different climatic and demand patterns. Future tasks include expanding the number of evaluation cases, obtaining more generalizable insights, and contributing to the spread of viable local energy projects through practical simulations.

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REFERENCE

[1] National Institute for Environmental Studies, Japan. National GHG Inventory Document of JAPAN; 2024 https://www.nies.go.jp/gio/en/aboutghg/index.html

[2] Fujimori S, Kainuma M, Masui T, Hasegawa T, Dai H. The effectiveness of energy service demand reduction: A scenario analysis of global climate change mitigation. Energy Policy 2014;75:379-91.

[3] Hirano Y, Fujita T. Simulating the CO_2 reduction caused by decreasing the air conditioning load in an urban area. Energy and Buildings 2016;114:87-95.

[4] Hirano Y, Ihara T, Yoshida Y. Estimating Residential CO_2 Emissions based on Daily Activities and Consideration of Methods to Reduce Emissions. Building and Environment 2016;103:1-8.

[5] Ministry of the Environment Government of Japan, Kyoto Protocol Target Achievement Plan (in Japanese) https://www.env.go.jp/content/900447426.pdf

[6] Deguenon L, Yamegueu D, Moussa kadri S, Gomna A. Overcoming the challenges of integrating variable renewable energy to the grid: A comprehensive review of electrochemical battery storage systems. Journal of Power Sources 2023;580:233343.

[7] Knuepfer K, Rogalski N, Knuepfer A, Esteban M, Shibayama T. A reliable energy system for Japan with merit order dispatch, high variable renewable share and no nuclear power. Applied Energy 2022;328:119840.

[8] Deng X, Lv T, Hou X, Xu J, Pi D, Liu F, Li N. Regional disparity of flexibility options for integrating variable renewable energy. Renewable Energy 2022;192:641-54.

[9] Hayashi Y. Japanese energy management in smart grid after the great East Japan earthquake. Electrical Engineering in Japan. 2014;189(2):20-5

[10] Hirano Y, Gomi K, Togawa T, Nakamura S, Ooba M, Fujita T. Multidisciplinary reconstruction support to evolve from disaster recovery to environmental creation. Environmental Information Science. 2017;46(1):47-52. (in Japanese)

[11] Shinchi town, UR Linkage, NTT Facilities, Keiyo plant engineering co. ltd., NEC global. Master plan formulation project for revitalization community building centered around the use of energy produced and consumed in Shinchi town. The 2016 smart community adoption promotion project; 2016. 138 p (in Japanese)

[12] Hirano Y, Nakamura S, Gomi K, Togawa T, Fujita T, Oba M. Introduction of low-carbon community energy systems by combining information networks and cogeneration-type district heating and cooling systems. In: Chaouki Ghenai and Tareq Salameh, Sustainable Air Conditioning Systems, IntechOpen, 2018;99-120.

[13] Hirano Y, Nakamura S, Togawa T, Fujita T, Adachi K: Smart Community Recovering from the Tsunami-Disaster: Case Study of the Community Energy Supply Project in Shinchi Town, Fukushima, Global Environmental Research 2021;24(2):199-206.