Research Project Report
Program for Asia-Japan Research Development, Asia-Japan Research Institute
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Research on Green Recovery and the Realization of Carbon Neutrality in East Asia

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Background and Significance of this Research

East Asia is simultaneously facing three major challenges: economic development, overcoming pollution, and preventing global warming. In response to the unprecedented “crisis” brought about by COVID-19, there is a growing need for a so-called “green recovery” and an approach that aims to address these challenges concurrently by revitalizing the economy through environmentally focused investments, such as climate change countermeasures, while also building a more resilient society.

Japan, China, and South Korea collectively account for approximately 30% of the world’s primary energy consumption and CO_2 emissions and have each declared “50-60” targets for Net Zero Emissions (Japan and South Korea by 2050, China by 2060) for carbon neutrality. However, around 90% of carbon emissions are energy-related, making issues such as the future of coal as a baseload power source, competition with renewable energy, the adoption or rejection of nuclear power, and the introduction of carbon emissions trading systems critical. International cooperation and policy innovation will be key to realizing a decarbonized society.

According to the scientific findings of the Sixth Assessment Report (AR6, physical science basis) announced by the IPCC this August, the internationally agreed 1.5°C threshold is alarmingly close, and there is an urgent call to accelerate global warming countermeasures—to act “faster, stronger, and higher.”

Against this backdrop, it is crucial to position carbon neutrality as a shared strategic challenge for East Asia and to converge toward an optimal solution achievable through green recovery, relying on collaboration among actors across different dimensions.

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Objectives

This study aims to contribute to the development of a systematic research framework that supports the realization of the "50-60 Targets"—namely, carbon neutrality by 2050 in Japan and South Korea and by 2060 in China—and the promotion of Green Recovery strategies in East Asia. By addressing multiple challenges in an integrated manner, the project seeks to build a roadmap that can harmonize economic growth, energy security, and environmental sustainability in the post-pandemic era.

The first objective is to develop an integrated assessment model and conduct scenario analyses that align with the "50-60 Targets." A nonlinear programming model will be constructed, emphasizing technological evaluation and policy analysis capabilities. Using this model, the project will assess both production-based and consumption-based CO_2 emission structures, while also evaluating the co-benefits of reducing pollutants such as SO_x and NO_x. Through a back casting approach, it will propose harmonized economic, energy, and environmental scenarios that guide the realization of carbon neutrality and Green Recovery.

The second objective focuses on the system evaluation of an optimal energy mix. Given that approximately 90% of carbon emissions are energy-related, the research will analyze changes in energy consumption patterns induced by COVID-19 and optimize energy supply and demand based on the 3E+S principle (Energy security, Economic efficiency, Environmental protection, and Safety). Special attention will be given to the cost competitiveness and mismatch issues related to coal as a baseload power source and new energy technologies, while also considering the potential of Carbon Capture and Storage (CCS) and Carbon Capture, Utilization, and Storage (CCUS) solutions. Furthermore, the study will apply root cause analysis to evaluate the status of nuclear power policies, technological capacities, human resources, and information systems in each country, thereby formulating evidence-based policy recommendations to strengthen nuclear security.

The third objective is to design and simulate an East Asia Emissions Trading System (EA-ETS). Building upon comparative studies with the EU-ETS, the project will propose a conceptual design for the EA-ETS and estimate marginal abatement cost curves for Japan, China, and South Korea using the integrated model. Sensitivity analyses will be conducted to evaluate the impact of implementing the EA-ETS. In addition, pilot virtual trading experiments will be carried out to simulate a functioning EA-ETS market, aiming to lay the groundwork for regional carbon market cooperation.

In addition to these core objectives, the study actively contributes to the United Nations Sustainable Development Goals (SDGs). Research on Green Recovery aligns with SDG Goal 1 (No Poverty), the evaluation of the optimal energy mix supports SDG Goals 7 (Affordable and Clean Energy) and 13 (Climate Action), and the scenario analyses and EA-ETS design contribute to SDG Goals 13 (Climate Action) and 17 (Partnerships for the Goals).

This project is characterized by its systems-based approach that seeks optimal solutions across multiple intertwined challenges, rather than addressing them in isolation. Although some foundational research exists, such as our publication *East Asia Low Carbon Community* by Springer Nature, research specifically targeting the realization of carbon neutrality in East Asia remains at an early stage globally. Thus, this project represents an innovative and timely contribution to an emerging research frontier.

Actual Activities

April 1, 2022–September 30, 2022

During this period, one postdoctoral researcher (PD) and one assistant researcher (AR) were employed. They independently carried out the entire process from issue identification to planning, evaluation, and implementation, with a focus on fostering international human resources through systematic training in quantitative analysis methods.

- **PD Jiahao Zhang** actively participated in academic seminars, built networks with researchers inside and outside the university, and prepared his first JSPS Young Scientists Grant application under the guidance of supervisors. He completed a related survey and began writing research papers aligned with the project's objectives.
- **AR Kyung-Ah Cheon** deepened her understanding of the project's purpose, engaged in research activities including co-authoring papers and book chapters, and managed project operations as an administrative assistant.

Main Achievements:

- PD Zhang conducted a survey on citizens' willingness to pay for carbon tax policies in Shanghai and authored a paper titled *A Review of the Progress of Carbon Tax-related Research and the Current Development of Carbon Tax Systems in East Asia*, preparing for presentation at the 2022 Energy and Resources Society Conference.
- AR Cheon collaborated on conference presentations and contributed to the book *Environmental Policies and Challenges in East Asia* (scheduled for publication in February 2023).

Additional Activities:

- Organized regular seminars and study groups for graduate students, including Japanese language support for international students.
- Graduate students (five M2 students) presented their research at the 2022 Environmental Economics and Policy Studies Conference (October 1, 2).
- **Expert meetings were held every three months** to discuss progress and refine the research direction.

October 1, 2022–March 31, 2023

The focus remained on systematic research activities and fostering young researchers.

- **PD Zhang** participated in the Graduate Research Project on "Global Governance and Sustainable Environmental Management," contributing to research discussions and mentoring.
- **AR Cheon** advanced her research on recycling societies in East Asia and supported students with paper proofreading and research advice.
- **Graduate students** assisted in organizing the "Japan-China Decarbonized Cities Forum" and acquired practical skills for international conference support.

Main Achievements:

- PD Zhang submitted papers on carbon tax pricing using conjoint analysis, presented at the AAPU Conference, and Imperial College Low-Carbon Energy Transition Forum.
- AR Cheon organized and managed 13 sessions of the Ritsumeikan Low Carbon Strategy Seminar and was awarded a JSPS KAKENHI Grant (2023–2026).

- Continued **expert meetings every three months** for interim evaluations and progress sharing.

April 1, 2023–September 30, 2023
From this period onward, Dr. You Li was appointed as the new specialized researcher (PD).

- **PD You Li** actively engaged in paper writing, international conference presentations, and graduate student mentoring through participation in research projects on global governance and sustainable environmental management.
- **AR Kyung-Ah Cheon** conducted fieldwork related to waste management systems in Hokkaido and Osaka, summarized findings for paper preparation, and continued administrative duties.
- **Graduate students** prepared for the 2nd Japan-China Decarbonized Cities Forum and presented at the 2023 Environmental Economics and Policy Conference.

Main Achievements:

- PD You Li published two SCI papers and submitted two additional manuscripts on solar radiation forecasting and decarbonization pathways.
- AR Cheon prepared for international fieldwork, with a Korea field survey scheduled.
- Continued **regular expert meetings every three months** to monitor progress.

October 1, 2023–March 31, 2024
Research activities intensified toward producing tangible outputs.

- **PD You Li** published papers in *Sustainable Cities and Society* and *Energy Proceedings*. He secured a competitive research grant for international collaboration and applied for JSPS Young Scientists funding.
- **Graduate students** expanded participation in conferences, publishing academic papers, and facilitating knowledge exchange events such as "Experience Sharing on SCI Paper Writing."

Additional Activities:

- Organized and hosted symposiums and workshops related to project themes.
- Continued **quarterly expert meetings** to discuss interdisciplinary linkages and project refinement.

April 1, 2024–September 30, 2024
In the first half of FY2024, project activities were further expanded and deepened.

- **PD You Li** focused on publishing high-impact papers, mentoring graduate students, and presenting at international conferences.
    - Published papers including *Interpretable Deep Learning Framework for Hourly Solar Radiation Forecasting* (*Applied Energy*, IF 10.1) and *Scenario Analysis for Energy Transition Integrating Global and Local Perspectives* (*Energy Proceedings*).
    - Previously presented at ICAE 2024 in Niigata and the 25th World Peace and Regional Socioeconomic Development Conference in Kagoshima
- **Graduate students** participated in the 2024 Environmental Economics and Policy Studies Conference, assisted in organizing the 3rd Japan-China Decarbonized Cities Forum, and led peer mentoring sessions.

Additional Activities:

- Organized **expert workshops every three months** with invited speakers to strengthen research directions.
- Hosted guest lectures and roundtables, inviting distinguished researchers from domestic and overseas institutions.
- Launched new initiatives for international collaborative research proposals.

October 1, 2024–March 31, 2025

During this period, research efforts were continuously strengthened through academic activities, international engagement, and researcher mentoring.

- **PD You Li**: Continued research on solar radiation forecasting and decarbonization strategies.
    - His paper *Interpretable Deep Learning Framework for Hourly Solar Radiation Forecasting Based on Decomposing Multi-Scale Variations* was published in *Human-centric Computing and Information Sciences*.
    - Another paper, *Scenario Analysis for Energy Transition Integrating Global and Local Perspectives*, was published in *Energy Proceedings*.
    - He presented at the CSA 2024 conference in Korea, receiving the Best Paper Award.

Additional Activities:

- Conducted regular expert meetings every three months.
- Provided intensive mentoring to graduate students and contributed to skill development workshops.
- Promoted international dissemination of research through conferences and collaborative forums.

Result and Perspectives

1. Development of a Refined Integrated Assessment Model

This study presents the development of a refined version of the Glocal-Century Energy Environment Planning (G-CEEP) model, designed to support strategic planning toward carbon neutrality at the community level. The model builds upon the traditional CEEP framework by integrating more granular technology-specific modules and coupling global objectives with localized constraints—hence the “glocal” character of the model.

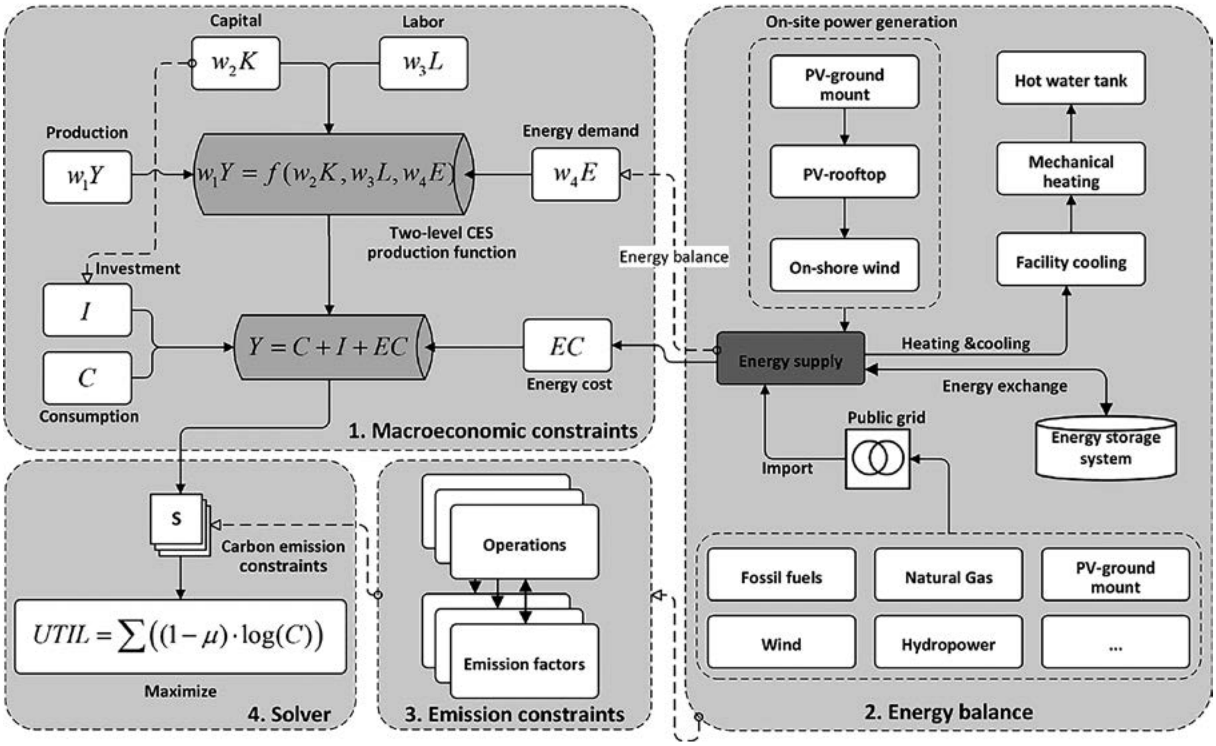


Figure 1. Glocal-Century Energy Environment Planning (G-CEEP) model

At its core, the model comprises three key modules:

(1) a **macroeconomic optimization module** structured around a Constant Elasticity of Substitution (CES) production function, allowing for flexible substitution among labor, capital, and energy inputs under technological constraints;

(2) a **detailed energy balance module** that simulates supply-demand interactions across electricity, heat, hydrogen, and biomass sectors; and

(3) an **emission and policy constraint module** that applies carbon budgets and policy timelines aligned with national net-zero targets.

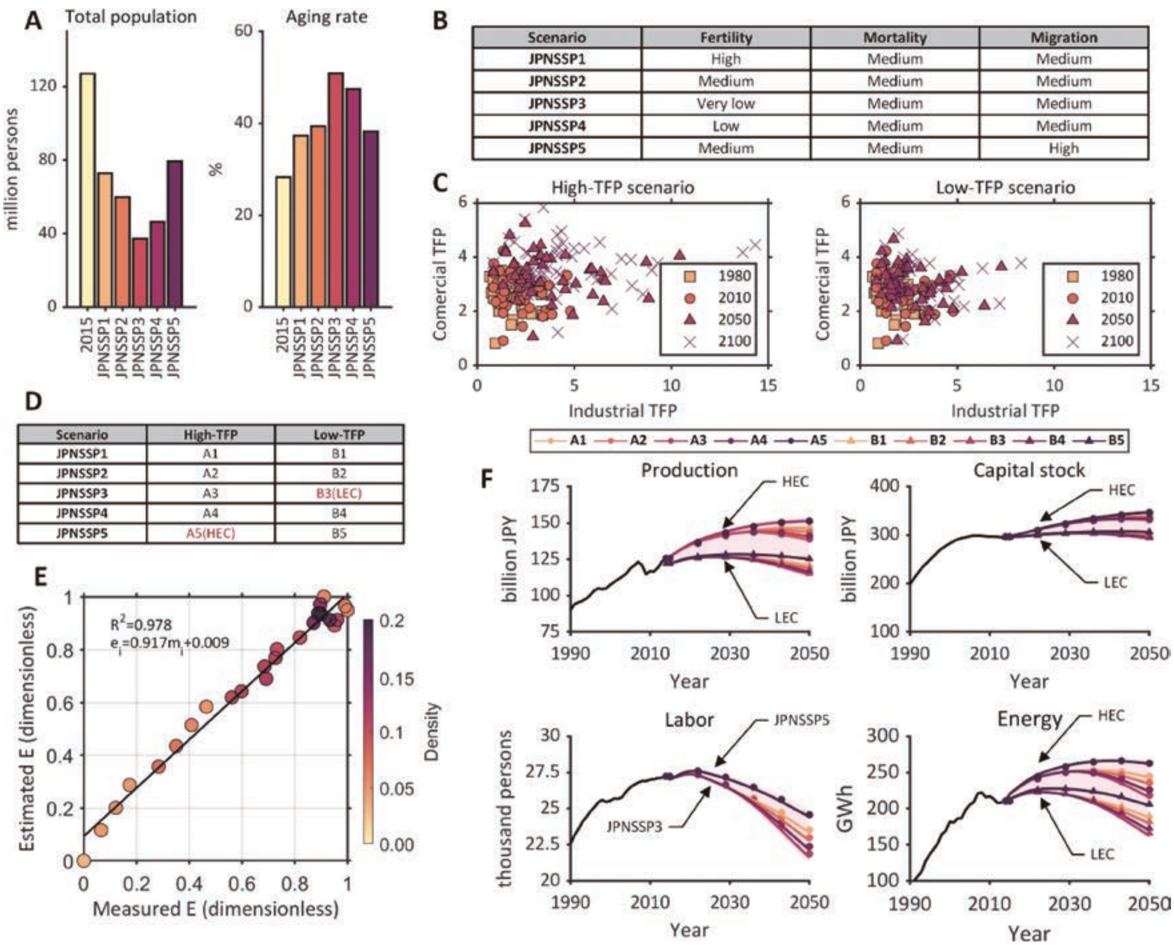
One of the model's innovations lies in its technology resolution. By explicitly modeling the capital costs, learning curves, efficiency limits, and dispatch characteristics of key low-carbon technologies—including solar PV, wind, hydrogen fuel cells, biomass cogeneration, and CCS-equipped fossil generation—the G-CEEP model allows for temporally optimized technology deployment paths. It also incorporates demand-side measures, such as building energy retrofits and electrification, enabling a full-chain analysis from primary energy supply to end-use services.

Importantly, the model operates under a **bottom-up meets top-down framework**, combining engineering-based cost and performance data with macroeconomic indicators like GDP growth, demographic change, and energy price projections. This hybrid design ensures internal consistency while enhancing the model's capacity to capture regional disparities and socioeconomic drivers of energy transitions.

In contrast to existing top-down IAMs (Integrated Assessment Models) that are often aggregated at the national or global level, the G-CEEP model enables **place-based energy planning**, offering insights into locally feasible technology mixes, investment timelines, and trade-offs between cost, equity, and sustainability. Its modular architecture also allows for easy adaptation to other regions or cities with varying resource endowments and infrastructure readiness.

2. Application to a Japanese Smart Community: Insights from Scenario Analysis

To demonstrate the utility and flexibility of the G-CEEP model, it was applied to a case study in the **Higashida Smart Community**, Japan—a region noted for its efforts in renewable energy adoption, distributed generation, and industrial decarbonization. This community-scale application enables a close examination of how specific technologies and policy pathways perform under real-world constraints, such as land availability, infrastructure readiness, and local demand profiles.



Scenario	Fertility	Mortality	Migration
JPNSSP1	High	Medium	Medium
JPNSSP2	Medium	Medium	Medium
JPNSSP3	Very low	Medium	Medium
JPNSSP4	Low	Medium	Medium
JPNSSP5	Medium	Medium	High

Scenario	High-TFP	Low-TFP
JPNSSP1	A1	B1
JPNSSP2	A2	B2
JPNSSP3	A3	B3(LEC)
JPNSSP4	A4	B4
JPNSSP5	A5(HEC)	B5

Figure 2. Macroeconomic scenarios assumptions

Six scenarios were designed and simulated, varying along two primary dimensions: total energy demand (high, medium, low) and technology availability (limited vs. fully available, including hydrogen and CCS). Each scenario was evaluated over a 30-year time horizon, with interim targets benchmarked against Japan's national 2030 and 2050 carbon neutrality goals.

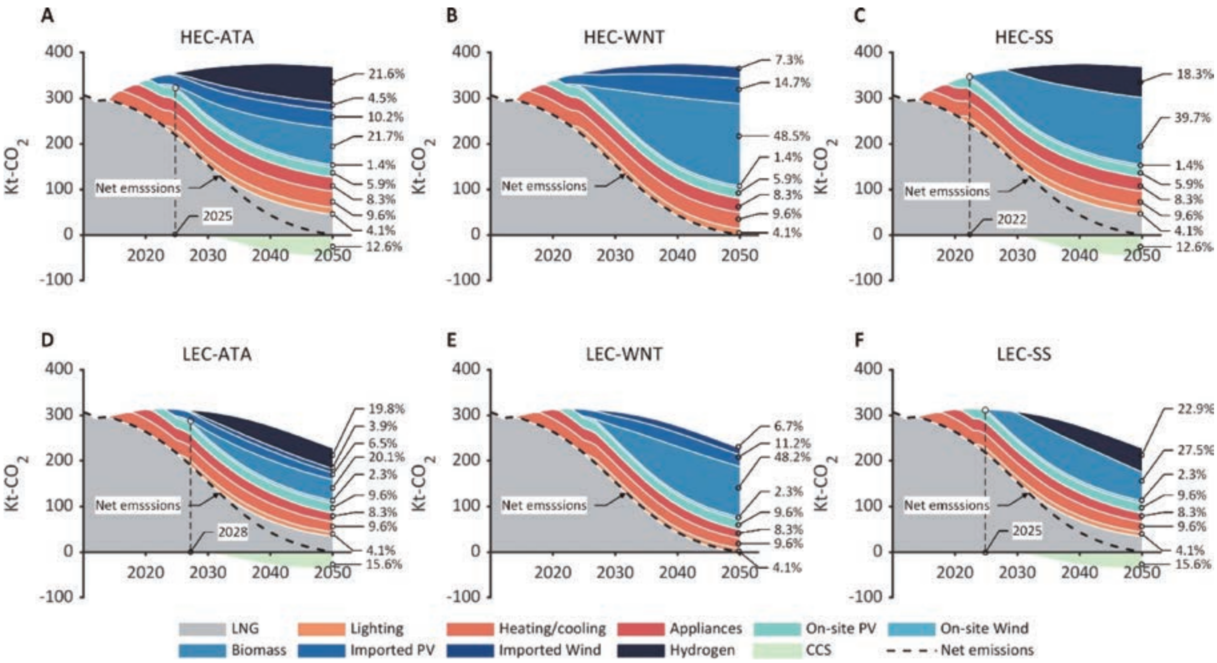


Figure 3. Energy-related CO2 emissions and carbon neutrality target realization pathways from 2010 to 2050

The objective was to identify economically and technically feasible transition paths that also minimize social disruption.

The simulation results yielded several critical insights:

- **Building sector efficiency** emerges as the most cost-effective intervention in the near term (2022–2030), particularly in retrofitting existing structures and improving HVAC systems. These measures reduce overall system pressure and delay the need for capital-intensive technologies.
- **Imported renewable electricity**—mostly from regional solar and wind resources—plays an important transitional role. Between 2025 and 2035, this external supply helps mitigate the temporal mismatch between local generation and consumption, while also buying time for domestic capacity building.
- In the **long-term phase (post-2035)**, decarbonization increasingly relies on **dispatchable, flexible resources** such as biomass cogeneration, hydrogen power, and fossil energy combined with carbon capture and storage (CCS). These technologies compensate for the intermittency of renewables and enable deep emission reductions during seasonal or peak-demand periods.

However, the model also reveals **systemic constraints**: even under optimistic scenarios, solar and wind penetration was economically capped at around 20–30% of total supply due to land-use competition, low capacity factors, and costly storage requirements. This highlights the importance of investing in **long-duration energy storage**, grid flexibility, and inter-regional energy exchange mechanisms.

Additionally, the cost of achieving net-zero differs significantly across scenarios. The most ambitious pathways involving hydrogen and CCS incur higher upfront investments but yield lower cumulative emissions and higher resilience in the long run. This implies that **early-stage policy support, including R&D subsidies and pilot infrastructure for hydrogen and CCS**, can reduce long-term costs and enhance system adaptability.

Finally, the case study emphasizes the need for **coordinated multi-level planning**. While national targets provide strategic direction, local energy transitions must be tailored to specific geographies and community characteristics. The G-CEEP model proves particularly effective in bridging this top-down–bottom-up gap by offering a decision-support framework for municipalities aiming to align local action with national climate commitments.

3. Assessment of Renewable Energy Potential Across Japanese Regions

In addition to the case study analysis, a comprehensive survey of renewable energy potential across Japan was conducted to better understand regional disparities and resource endowments. Figure 4 illustrates the estimated renewable energy supply capacity, broken down by energy type—such as photovoltaic (PV) farms, rooftop PV, onshore and offshore wind, biomass (wood and waste), hydro, and geothermal resources—for each major regional block in Japan.

The findings reveal substantial heterogeneity in renewable energy potential:

- **Hokkaido** and **Tohoku** regions exhibit the highest renewable energy capacities, primarily due to abundant offshore wind and large-scale solar farm potential. Hokkaido alone could supply approximately 38% of Japan's total renewable potential, making it a critical region for large-scale renewable deployment.
- In contrast, more densely populated and industrialized regions such as **Kanto**, **Kansai**, and **Chubu** show relatively limited renewable potentials (around 4% to 7%), constrained by urban land scarcity and lower wind resource availability.
- **Kyushu** and **Shikoku** offer moderate renewable potentials, driven largely by solar and modest biomass resources, while **Okinawa** has the lowest renewable share at only 1.5%, mainly due to its geographic and scale limitations.

A significant observation from the regional analysis is that offshore wind dominates in northern areas, while solar PV contributes more heavily in southern and western regions. Biomass and geothermal resources provide supplementary options but remain relatively small in share compared to wind and solar.

These findings suggest that a **regionally differentiated strategy** will be essential for Japan's national carbon neutrality goals. Northern regions like Hokkaido and Tohoku could become major exporters of renewable electricity, necessitating robust grid reinforcement and inter-regional transmission projects. Meanwhile, urbanized areas must focus on energy efficiency improvements, rooftop solar, and demand-side management to complement limited local renewable supplies.

The regional disparities identified emphasize the importance of spatial planning and coordinated energy policies that leverage regional strengths while ensuring national-level energy security and system stability.

Figure 4. Mapping Japan's Renewable Energy Potential

4. Macroeconomic and Energy Demand Projections for Japan

We projected Japan's long-term macroeconomic and energy consumption trends to serve as foundational inputs for the decarbonization scenario analysis. The results reveal several critical structural transitions that will shape the feasibility and timing of carbon-neutral energy planning.

First, Japan's population is expected to decline steadily from 2019 to 2050, with a particularly sharp decrease after 2030. By mid-century, the total population is projected to fall below 100 million. Simultaneously, the aging rate is forecasted to exceed 40%, posing significant challenges to labor supply, productivity, and national energy demand profiles. This demographic shift implies a transition toward lower overall energy demand, but with growing pressure on the social support and infrastructure systems.

Second, there is substantial regional variation in economic productivity. Industrial and commercial total factor productivity (TFP) levels differ widely across prefectures. While some regions demonstrate sustained productivity growth and resilience—such as Yamaguchi, Tokushima, and Miyagi—others are projected to experience stagnation. These disparities suggest the need for regionally tailored decarbonization strategies that reflect varying capacities for economic adaptation and technological adoption.

Third, Japan's gross production (GDP) and capital stock are expected to grow moderately over the coming decades, supported by ongoing investment and technological progress. While growth is not rapid, it is stable enough to support structural energy shifts without causing major economic disruption. However, a declining population will exert downward pressure on consumption and public revenue, reinforcing the importance of cost-effective and phased energy transitions.

Finally, national final energy consumption is projected to decline from approximately 14 EJ in

2020 to around 9 EJ by 2050. This reduction is driven by improvements in energy efficiency, the electrification of end-use sectors, and declining industrial output in some regions. The energy outlook under different socioeconomic pathways (e.g., JPN-SSP2 and JPN-SSP5) confirms that Japan's net-zero target is within reach, provided that appropriate demand-side measures and technology policies are implemented.

These findings highlight the interdependence between demographic change, regional productivity, and energy transition capacity. An effective decarbonization policy will require not only technological deployment but also proactive management of socioeconomic and demographic constraints over the coming decades.

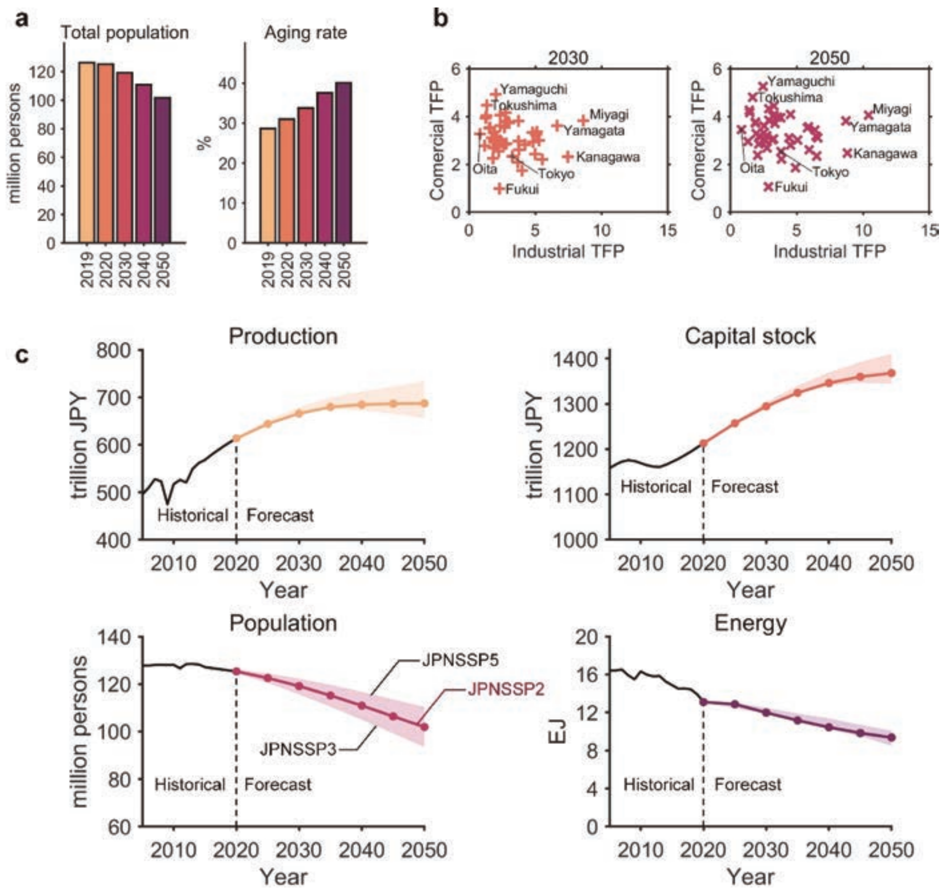


Figure 5. Long-Term Socioeconomic and Energy Forecasts for Japan (2020–2050)

5. Future Perspectives

Looking ahead, this study provides a foundation for more regionally adaptive and technologically diversified pathways toward carbon neutrality in Japan, South Korea, China, and beyond. As energy transitions become increasingly intertwined with demographic shifts, economic restructuring, and geopolitical uncertainties, future research must go beyond static scenario evaluation. Dynamic, multi-scale models—such as the G-CEEP framework developed here—should be further expanded to include behavioral responses, inter-sectoral feedback, and cross-border energy flows.

Moreover, the growing spatial disparity in renewable energy potential and productivity calls for a more integrated planning approach, linking land use, grid development, and industrial clustering strategies. As storage technologies and hydrogen infrastructure evolve, their deployment should be assessed not only based on cost-effectiveness, but also on system-wide flexibility and equity impacts across regions.

Finally, deeper collaboration between researchers, policymakers, and local stakeholders will be crucial to operationalize the "glocal" transition vision. By combining global carbon goals with local constraints and capabilities, Japan can serve as a replicable model for other countries navigating similar demographic and technological transformations.

Project Members and Roles

Title	Name	Affiliation	Position/ Academic Year	Specialization
Project Leader	Weisheng Zhou	College of Policy Science	Professor	Energy and Environmental Policy, Policy Engineering
Project Member	Kenichi Nakagami	OIC Comprehensive Research Organization	Professor	Water Resources and Environmental Policy, Policy Science
Project Member	Noboru Miyawaki	College of Policy Science	Professor	International Public Policy, Security Policy
Project Member	Katsuyuki Nakano	College of Policy Science	Associate Professor	Environmental Management, Environmental Impact Assessment
Project Member	Xuepeng Qian	Graduate School of Global Environmental Studies, Sophia University	Professor	Industrial Ecology, System Assessment
Project Member	Wakana Takahashi	Faculty of International Studies, Utsunomiya University	Professor	Global Environmental Policy, International Environmental Cooperation
Project Member	Hongbo Ren	Shanghai University of Electric Power, School of Energy and Mechanical Engineering	Professor	Distributed Energy Systems, System Analysis
Project Member	Kazuo Matsushita	Kyoto University	Professor Emeritus	Environmental Economic Policy, International Governance
Project Member	Soocheol Lee	Faculty of Economics, Meijo University	Professor	Environmental Economics
Project Member	Noritaka Haga	Faculty of Regional Development Studies, University of Nagasaki	Lecturer	Environmental Economics
Project Member	Hyelim You	Faculty of Business Administration, Nagoya University of Commerce and Business	Associate Professor	International Relations, International Trade Theory
Specialized Researcher/ Researcher	You Li	AJI	Senior Researcher (2023-2025)	Distributed Energy Systems, Development of Evaluation Models
Specialized Researcher/ Researcher	Jiahao Zhang	AJI	Senior Researcher (2022-2023)	International Energy and Environmental Policy
Specialized Researcher/ Researcher	Kyung-Ah Cheon	RCS	Researcher	Waste and Environmental Policy, Korean Studies
Graduate Student	Chong Zhang	Graduate School of Policy Science	D2	International Energy and Environmental Policy
Graduate Student	Jin Toyohara	Graduate School of Policy Science	D2	International Energy and Environmental Policy
Graduate Student	Ze Ran	Graduate School of Policy Science	D1	International Energy and Environmental Policy
Graduate Student	Liu Cao	Graduate School of Policy Science	M2	International Energy and Environmental Policy

Selected List of Publications

**: Corresponding Author, +: Co-corresponding Author. (Project Member)*

Journal Papers

1. Li, Y., Zhou, W., Wang, Y., Miao, S. *, Yao, W., and Gao, W. 2025. Interpretable Deep Learning Framework for Hourly Solar Radiation Forecasting Based on Decomposing Multi-Scale Variations. *Applied Energy*, 377, 124409.
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Books

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