Economic Contributions and Green Job Implications of Japan’s Energy Transition: An Integrated Assessment of Decarbonization Scenarios in Kyushu Region

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Economic Contributions and Green Job Implications of Japan's Energy Transition: An Integrated Assessment of Decarbonization Scenarios in Kyushu Region.

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Abstract: *This study examines the economic and employment impacts of renewable energy systems (RES) in Kyushu, Japan, focusing on solar, wind, and biomass power. Using the Leontief input-output model, the research quantifies job creation and economic contributions from renewable energy investments. Employment coefficients highlight indirect, construction, and operational job impacts. Biomass power, with its extensive supply chain, is the largest contributor to job creation and economic output, generating 7,736 jobs and 32.4 million JPY annually. Wind power follows, with significant contributions from moderate operational demands, creating 1,824 jobs and adding 3 million JPY to the economy. Solar power, despite its efficiency, generates fewer jobs and economic impact due to minimal maintenance requirements, contributing 348 jobs and 1.2 million JPY. The study underscores the multifaceted benefits of renewable energy, emphasizing broader socio-economic impacts beyond energy output. The findings highlight the importance of integrating renewable energy investments with economic development strategies, illustrating how such initiatives can drive GDP growth, industrial expansion, and energy security, advancing sustainable economic growth and decarbonization goals in Kyushu.*

Keywords: *Renewable Energy systems; Economic Impact; Job Creation; Sustainable Development; Leontief input-output model.*

1. INTRODUCTION

The concept of green jobs originates in part from an authentic commitment to sustainability and environmental stewardship. These roles encompass a diverse array of occupations driven by public and private sector investments in the green economy. The primary focus of these positions is on environmental preservation, restoration, and sustainability (1) (2).

The creation of employment opportunities in renewable energy is crucial in mitigating climate change and reducing the human ecological footprint. Over the past decade, the renewable energy sector alone has generated over five million green jobs, spanning policy development, technological advancements, investment in technology, and infrastructure development, all of which facilitate the integration of renewable energy into the energy mix. The transition towards carbon neutrality in developed and developing nations is expected to drive GDP growth through job creation, enhance energy independence, support industrial growth, and foster sustainable economic development. According to the 2023 annual report by the International Renewable Energy Agency (IRENA) and the International Labor Organization (ILO), global employment in renewable energy reached 14 million in 2022, marking a one million increase from 2021 and a significant rise from 7.3 million in 2012 (3).

In June 2019, Japan submitted its long-term low greenhouse gas emission development strategy, commonly known as the mid-century strategy, to the United Nations Framework Convention on Climate Change (UNFCCC) in accordance with Article 4 of the Paris Agreement (Government of Japan 2019) (4). This strategy reiterated Japan's commitment to reducing greenhouse gas emissions by 80% by 2050, a target initially outlined in earlier documents (Ministry of the Environment 2012; Government of Japan 2016). Subsequently, in October 2020, Prime Minister Suga announced a new pledge for Japan to achieve net-zero emissions by 2050 (Suga 2020) (5). However, achieving deep decarbonization poses challenges for Japan, especially in the wake of the 2011 Fukushima nuclear disaster. Issues such as the complexities surrounding nuclear restarts and the increased reliance on coal-fired power have created

uncertainty about how Japan will navigate its decarbonization objectives. Incentive-driven decarbonization techniques have been employed in Japan to help improve the phase of transition from a fossil fuel-based economy (6).
According to the IRENA report, solar photovoltaic (PV) technology is the largest employer in the renewable energy sector, driven by significant investment and deployment. Solar PV, alongside wind power, has shown the most dynamic growth in both capacity and employment. In 2022, global employment in renewable energy reached 13.7 million, a notable increase (3).
Job creation sensitivities to energy transitions are assessed in the Japan Model Intercomparison Project on long-term climate policy, JMIP scenarios from the Energy Modeling Forum 35, which explore diverse climate and energy policy pathways for Japan (7). These scenarios focus on deep mitigation and low demand, emphasizing the importance of reducing energy demand for flexible mitigation actions and cost-effective emission reductions. The Leontief Input-Output (IO) model surpasses AIM/End-use[Japan] and TIMES-Japan partial equilibrium (PE) models by integrating the energy system with the broader macro-economy (8). Unlike PE models, which isolate energy systems and neglect sector interdependencies and indirect supply chain impacts, the IO model captures these dynamics. This comprehensive approach allows for a more accurate analysis of economic and social impacts, such as local value-added and employment levels, thus providing a more holistic understanding of labor demand and the economic effects of energy transitions (9). Linking IO analysis with scenario modeling effectively addresses the limitations of PE models (10).

2. PROBLEM FORMULATION

In this research, we aim to quantify the contribution of renewable energy (RE) technologies to job creation in Japan using data from the JPY2019 input-output tables. Our objective is to calculate the employment coefficient, E_{co}, representing the extent of job creation attributed to RE technologies, specifically solar E_{co_PV} , wind E_{co_W} , and biomass E_{co_B}. This coefficient is incorporated into the following equation to determine the total number of jobs created JT in each project scenario:

$$JT = E_{co\_PV}.G_{PV} + E_{co\_W}.G_W + E_{co\_B}.G_B \qquad \text{(I)}$$

Here, G_{PV}, G_W , and G_B denote the generated capacity for solar, wind, and biomass power systems, respectively.

To achieve this, the Leontief Input-Output (IO) model and Cobb-Douglas production function are combined to provide a comprehensive framework for analyzing the economic impact of changes in demand across sectors is utilized. The fundamental function is illustrated in (II).

$$Q = [I - Y]^{-1}.d \qquad \text{(II)}$$

where Q is the total output per sector, Y is the intermediate input coefficient matrix, and d represents the total final demand vector.

The employment coefficient E_{srt} is formulated for the s^{th} sector in region r or country within a year t, is defined by equation (III).

$$E_{srt} = \frac{1}{p_{s,r,t}}.L^d_{s,r,t} \qquad \text{(III)}$$

where $L^d_{s,r,t}$ denotes the regular employment opportunity and $p_{s,r,t}$ is the total production output for the s^{th} sector in region r in year t. The values for $L^d_{s,r,t}$ are extracted from the JPY2019 input-output tables (11).

Additionally, the study explores the economic contribution of RE technologies by computing changes in the final demand impact coefficient. By varying the demand vector d in the input-output model, we can model the economic impact due to changes in employment in renewable energy projects. Equation (IV) points out the computation of change in final demand, ΔF_j, for sector j based on the wages and employment coefficients of green jobs. L_{ij} are the elements of the Leontief inverse matrix, and ΔY is the change in total economic output.

$$\Delta Y = \sum_i \left(\sum_j L_{ij} \Delta F_j\right) \qquad \text{(IV)}$$

The resulting data provides insights into the broader economic benefits of RE deployment, including GDP growth, industry expansion, and enhanced energy security. This approach helps us understand the ripple effects of RE investments across various economic sectors, highlighting their potential to drive sustainable economic development.

activities, accounting for direct or indirect social impacts and supply chain interdependencies.

The technical formulation of the Leontief input-output model involves constructing an IO table that represents the economic sectors and their interdependencies. Each sector's output is

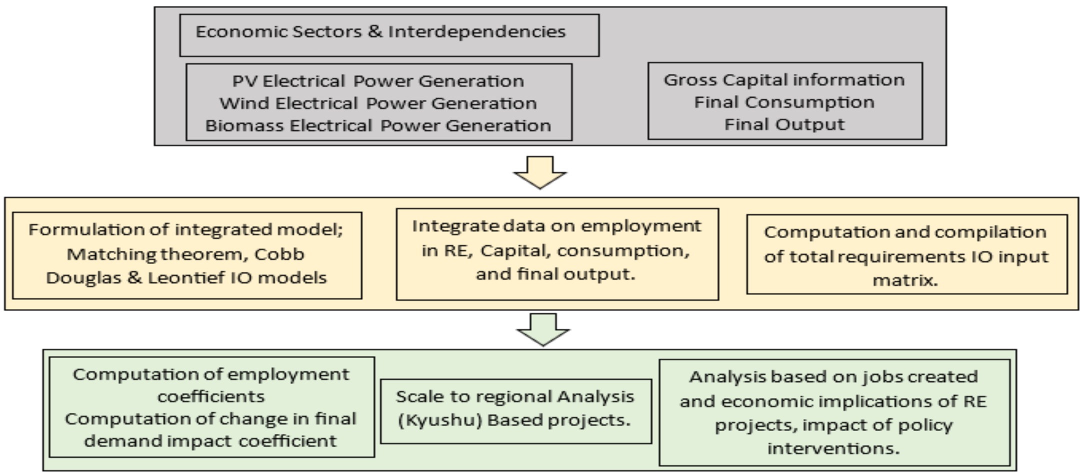

Figure 1: Methodology flow chart.

3. METHODOLOGY

The Leontief input-output model was adapted to assess green job employment in the solar, wind, and biomass sectors. This adaptation involves an integration of the matching model, the Cobb-Douglas production model, and the Leontief input-output model. This approach allows for a more holistic understanding of how various factors, such as technology, policy interventions, economic shocks, and labor market dynamics, affect job creation. This study integrates observations from the renewable energy (RE) sector, Wind, and Biomass Systems, which provide detailed data on generation capacity and technology mix, into the national input-output (IO) framework. The approach effectively captures inter-sectoral transactions within Japan's macroeconomy. This is achieved by the combination of direct and indirect detailed RE data within the Japan IO tables, then mapping the flow of goods and services, including those induced by energy transition activities. The framework quantifies job creation across all sectors from investments in RE capacity and generation

expressed as a function of inputs from other sectors, forming a system of linear equations. This model uses a direct requirements matrix, also known as the Leontief matrix, which details the input coefficients required from each sector to produce one unit of output in another sector. By inverting the Leontief matrix, we obtain the total requirements matrix, which captures both direct and indirect input requirements across the entire economy.

The IO tables are analyzed to compute the direct and indirect employment coefficients in renewable energy integration, highlighting the job impacts of different energy transition scenarios.

The computation of Change in Final Demand using the Leontief input-output model involves altering the final demand vector to reflect increased investment in green jobs. The inverse Leontief matrix augments this change to determine the resulting equivalent output change across sectors. The study is further scaled down to reflect green job creation and economic contribution in the Kyushu region of Japan, considering different scenarios where solar, wind, and biomass power plants have been installed.

By localizing the results of the national IO analysis, the research captured region-specific inter-sectoral dynamics and job creation impacts. The detailed input coefficients for RE sectors were adjusted based on regional data, and scenarios included varying levels of RE deployment to assess their economic and employment impacts accurately. The jobs and change in final demand coefficients are applied in the scenarios within Kyushu to reflect the actual green job creation and economic impact potential in the region. This regional focus provides insights into how localized RE investments contribute to job creation and economic growth, considering regions such as Kyushu, where massive investment in clean energy generation infrastructure has been established.

Table 1: Selected Solar power plants in Kyushu, Japan (12)

Solar Power Plant	Capacity (MW)	Output (GWh)
JRE Aso Takamori	62.5	71.5
JRE Fukuoka Akamura	2.4	2.71
Fukuoka Mega	0.99	1.11
Kanoya - Kagoshima	1.14	1.2
Uruma - Okinawa	12.2	15.04

Table 2: Selected Wind farms in Kyushu, Japan *(12)*

Wind Power Plant	Capacity (MW)	Output (GWh)
Onitayama	16	41
Onitayama 2	12.8	28.7
JRE Ikitsuki	8.6	23.8
Hibikinada Park	6.6	14.2
Hibikinada Offshore	220	500

Table 3: Selected Biomass Power Plants in Kyushu, Japan *(13)*

Biomass Power Plant	Capacity (MW)	Output (GWh)
Buzen	74.95	500
Satsuma	1.99	14.04
Saiki	50	316
Tobu - Fukuoka	29.2	195
Nakagusuku	49	330

3.1 Criteria for Consideration of RES power plants

The clean energy policies in Kyushu target an increase in the share of renewable power generation sources. Kyushu's transition plan aims at strengthening its renewable energy capacity to 5 GW by 2030. The intent includes developing its energy service business, creating a sustainable community, and reinforcing business foundations. A sustainable community in this regard promotes environmental health, economic vitality, and social well-being. In this case, Kyushu seeks to utilize renewable energy to maximize resource efficiency, support local economies, and ensure social equity. Key elements include green infrastructure, quality of life improvements, human preservation, and active community engagement, fostering long-term stability and resilience for all residents. Investing in renewable energy within a sustainable community creates green jobs, which significantly contribute to economic vitality. These jobs include roles in solar, biomass, and wind energy installation, maintenance, and operations, as well as in energy efficiency and environmental protection. Green jobs not only provide employment opportunities and enhance local economies but also promote sustainable practices that align with the community's environmental goals. This dual impact supports economic resilience and growth while fostering a healthier environment, exemplifying the core principles of a sustainable community. Table 1Table 2Table 3 represent selected solar, wind, and biomass renewable energy systems (RES) power projects in the Kyushu area. The capacity and annual power generation for each power plant are indicated in these tables. The main feedstock utilized in the biomass power plants in

Table 2: Selected Wind farms in Kyushu, Japan

Wind Power Plant	Capacity (MW)	Output (GWh)
Onitayama	16	41
Onitayama 2	12.8	28.7
JRE Ikitsuki	8.6	23.8
Hibikinada Park	6.6	14.2
Hibikinada Offshore	220	500

Table 3 includes palm kernel shell (PKS), wooden pellets, unused timber, general waste, lumbering end materials, and poultry manure.

4. RESULTS AND DISCUSSIONS

4.1 Employment Coefficient:

Table 4 represents the calculated values of employment coefficients (person-years per GWh) according to the methodology presented in section 3.0. In this determination, the employment coefficient is based on two facets: direct and indirect employment. Direct green jobs refer to construction, installation, operation, and maintenance works, while indirect green jobs refer to support jobs such as logistics, training, transportation, professional services, and other related work areas. This study denotes vacancies created in operational and maintenance work prospects (Op-Jobs) and employment opportunities in construction and installation jobs (Con-Jobs) to illustrate direct employment. On the other hand, indirect employment opportunities are termed Ind-jobs.

Table 4: Employment Coefficients

Employment Coefficients	Con-Job Coeff.	Op-Job Coeff.	Ind-Job Coeff.
Solar PV Power	0.6856	0.2101	2.905
Wind Power	0.6069	0.12513	2.268
Biomass Power	0.6768	3.1620	1.870

For Solar PV Power, 0.6856 construction jobs, 0.2101 operational jobs, and 2.905 indirect jobs are created per GWh. Wind Power generates 0.6069 construction jobs, 0.12513 operational jobs, and 2.268 indirect jobs per GWh. Biomass Power creates 0.6768 construction jobs, 3.162 operational jobs, and 1.870 indirect jobs per GWh.
These coefficients are applied in selected PV, wind, and biomass power plants in the Kyushu area to demonstrate the impact on employment wherever local governments invest in renewable energy power generation systems. Figure 2 illustrates solar power plant employment based on annual power generation. The JRE Aso Takamori solar power plant, with an installed capacity of 62.5 MW and an annual output of 71.5 GWh, creates 49 construction and installation jobs, 15 jobs in operations and maintenance, and 207 indirect jobs, resulting in a total of 271 jobs. The Fukuoka Mega solar power plant has the lowest job creation due to its low annual generation of 1.11 GWh, corresponding to its capacity of 0.99 MW.

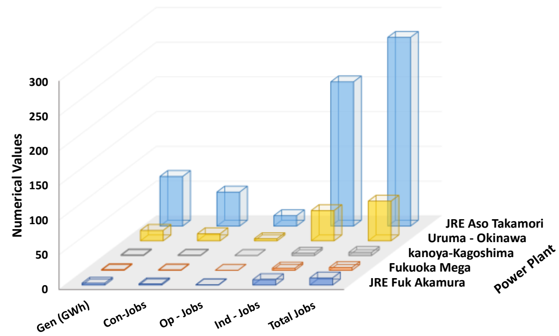

Figure 2:Selected solar power plants in Kyushu.

The Hibikinada offshore wind farm creates a total of 1,500 green jobs, followed by the Onitayama wind farm with 120 green jobs. The fewest jobs are created by the Hibikinada Park plant, with 42 jobs, as shown in Figure 2. For the selected biomass power plants in the Kyushu area, Buzen and Nakagusuku have the highest installed capacities of 74.9MW and 49MW, respectively. These two biomass plants generate an annual output of 830GWh and create a total of 4800 green jobs per year. The Saiki, Tobu, and Satsuma biomass power plants generate 316GWh, 195GWh, and 14GWh annually, respectively. This leads to an additional 3000 jobs. In this scenario, 15 electrical power plants have been assessed within Kyushu Island. According to Figure 2, 3, Figure 3, a total of 9900 green jobs are created from an annual generation of 2055 GWh.

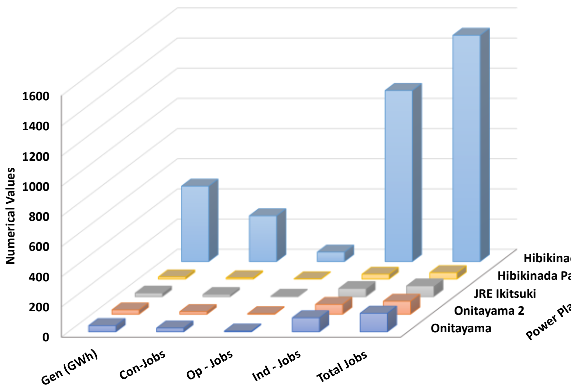

Figure 3: Selected wind power plants in Kyushu.

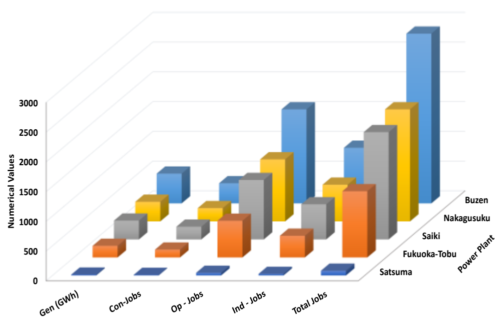

Figure 4:Selected biomass power plants in Kyushu.

4.2 Economic Contribution

The economic contribution reveals how wages spent by green job workers circulate through the economy, affecting various sectors. The result is a comprehensive monetary assessment of the economic impact, illustrating the contribution of green jobs to overall economic growth and sustainability.

Table 5: Final demand impact coefficients

Final Demand Impact Coefficients	Con-Jobs	Op-Jobs	Ind-Jobs
Solar PV Power	0.33	0.11	0.28
Wind Power	0.19	0.07	0.13
Biomass Power	0.21	0.34	0.27

Table 5 shows the proportion of income earned from every job created in construction, operation, and indirect opportunities that contribute to the economic growth of the region or country. Biomass operation jobs contribute the highest portion of 34%, which can be attributed to many jobs created during operation due to the extensive fuel supply chain, maintenance and operations of complex machinery, monitoring, and compliance with environmental regulations, local sourcing that boosts community employment, and continuous research and development efforts towards technology and efficiency improvement.

PV and wind power plants have lower economic contributions, 11%, and 7%, respectively, and create fewer jobs during the operation stage because they require minimal maintenance and human intervention once installed. These systems lack the continuous fuel supply chain needed by biomass plants, eliminating jobs related to fuel processing and transportation. Their long operational lifespan and efficiency of scale mean fewer operational staff are needed. Advanced automation and monitoring technologies further reduce labor requirements, resulting in fewer job opportunities and lower economic impact during their operational phase.

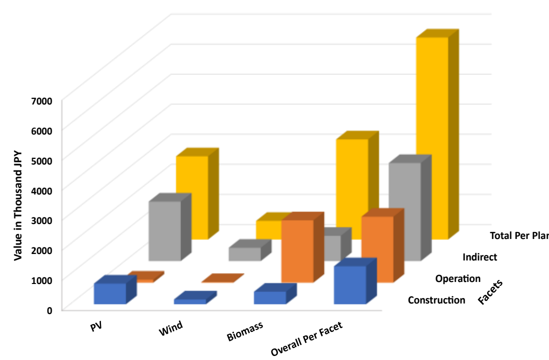

Figure 5:Economic Contribution per item.

The economic contribution of solar, wind, and biomass energy projects is substantial, as reflected in Figure 5 for the total sum of jobs created across different facets: construction, operation, and indirect impacts. During the construction phase, these renewable energy projects generate significant economic activity, contributing 1263 thousand JPY. This facet involves substantial investment in labor and services required to build the facilities. The construction jobs not only provide direct employment but also stimulate local economies through the purchase of goods and services, supporting regional growth.

In the operation facet, these projects contribute 2194 thousand JPY. While solar and wind power plants have lower labor demands due to automation and minimal maintenance requirements, biomass plants necessitate a higher workforce. This is due to their need for ongoing fuel supply management, extensive equipment upkeep, and environmental compliance activities. Consequently, biomass plants provide more job opportunities during operation, enhancing local economic activity and stability.
The indirect and induced jobs facet accounts for a significant 3262 thousand JPY. Indirect jobs are generated in sectors that support renewable energy operations, such as manufacturing, logistics, and maintenance services. Induced jobs arise from the spending of incomes earned by workers in both direct and indirect roles, further stimulating economic growth. These jobs create a multiplier effect, where increased spending leads to additional employment and business opportunities in the community.

The contents of Figure 5 can, therefore, be summarized to mean the economic contributions of solar, wind, and biomass projects are multifaceted, encompassing direct construction and operational jobs as well as indirect employment. These projects not only provide essential renewable energy but also drive significant economic growth, creating a ripple effect of job creation and economic benefits across various sectors. The substantial investments and continuous employment opportunities fostered by these renewable energy initiatives highlight their crucial role in promoting sustainable economic development.

The comparative analysis in examines the three combined renewable energy systems in Kyushu: solar power, wind power, and biomass power, based on their annual generation output (in GWh), green job creation, and economic contribution (in 1000 JPY).

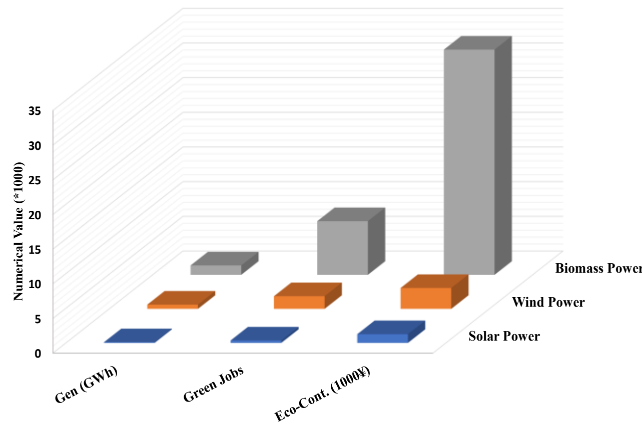

Figure 6:Comparative Analysis for the three combined RES Power Plants

Solar power, with an annual generation output of 91.55 GWh, stands out for its efficiency in energy production but lags behind wind and biomass power in total electricity generated. It contributes 348 green jobs and an economic impact of 1.255 million JPY, reflecting its lower labor intensity and economic output compared to the other two systems.
Wind power, generating 607.76 GWh annually, surpasses solar power significantly in electricity production. It creates 1824 green jobs and contributes 3.006 million JPY to the economy. Wind power's higher output and employment figures underscore its more significant economic impact compared to solar power, despite requiring moderate operational and maintenance efforts.
Biomass power emerges as the most productive, generating 1355.04 GWh annually, which exceeds the combined output of solar and wind power. It leads in green job creation with 7736 positions and makes a substantial economic contribution of 32.482 million JPY. The robust performance of biomass power highlights its extensive operational demands and supply chain complexities, which contribute significantly to both employment and economic output.

However, solar power demonstrates efficiency in energy generation; it falls short in job creation and economic impact compared to wind and biomass power. Wind power balances moderate generations with substantial economic contributions and job creation. Biomass power, despite its operational complexity, leads in both electricity generation and economic impact, making it a pivotal player in sustainable energy transitions due to its significant contributions across employment and economic sectors. These findings underscore the varied impacts of renewable energy sources, emphasizing the importance of considering not just energy output but also broader economic and employment implications in advancing sustainable energy solutions.

5. CONCLUSION

This study provides a comprehensive analysis of the economic and employment impacts of renewable energy systems in Kyushu. The findings reveal that biomass power, with its highest annual generation output and extensive supply chain, creates the most substantial economic contributions and green job opportunities. Wind power, while generating less electricity than biomass, still contributes significantly to the economy and job market due to its moderate operational demands. Solar power, though efficient in energy production, shows lower economic and employment impacts due to minimal maintenance requirements and automation.

Kyushu's clean energy policies aim to increase renewable power generation to 5 GW by 2030, focusing on developing sustainable communities and enhancing local economies. This transition is expected to create numerous green jobs across solar, wind, and biomass sectors, fostering economic vitality and social well-being. The study underscores the importance of considering both energy output and broader socio-economic benefits in advancing sustainable energy solutions. Overall, the integration of renewable energy systems in Kyushu not only supports decarbonization goals but also drives significant economic growth and employment, highlighting the multifaceted benefits of renewable energy adoption.

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