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Gima, Hiroki

Department of Applied Science for Electronics and Materials, Interdisciplinary Graduate School  
of Engineering Sciences, Kyushu University

Yoshitake, Tsuyoshi

Department of Applied Science for Electronics and Materials, Interdisciplinary Graduate School  
of Engineering Sciences, Kyushu University

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# A Comparative Study of Energy Security in Okinawa Prefecture and the State of Hawaii

Hiroki Gima\*, Tsuyoshi Yoshitake

Department of Applied Science for Electronics and Materials,  
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University  
6-1 Kasuga-koen, Kasuga, Fukuoka 816-8580, Japan

\*Author to whom correspondence should be addressed  
E-mail: hiroki\_gima@kyudai.jp

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The energy securities of Okinawa Prefecture and the State of Hawaii, both of which are isolated islands in the Pacific Ocean, were studied by comparison. While both islands depend on thermal power for more than 80% of their energy needs, power generation methods differ between them. The cost of energy supply in Okinawa is low because electrical energy is produced primarily by coal-fired power stations, whereas in Hawaii it is extremely high because oil, which is extensively used for various purposes such as airplanes and vehicles, is the energy source for most thermoelectric power stations. At present, Hawaii is installing renewable energy facilities as a test case for a next-generation energy-mix in the USA. On the other hand, Okinawa prefers energy security and low costs, similar to the strategy of Japan as a whole, since Japan is at high risk of natural disasters.

Keywords: Island energy security, Energy policy, Energy best-mix

## 1. Introduction

Energy security is defined the ability to continually secure sufficient energy to maintain civil life, economic and industrial activities, and the environment<sup>1,2,3</sup>. Energy supply and demand are key for the survival of a country, and competition for natural resources is fierce. In the short-term, energy security comprises the immediate management of fluctuations in energy demand and supply. Long term considerations also include appropriate investment in the energy supply and environmental conservation. Thus, it is important to consider energy security in order to overcome the trilemma of economic growth, environmental conservation, and resource security.

In this way, the study of islands is attracting much attention in terms of future realization of sustainable societies, due to the unique socio-economic characteristics, such as remoteness, smallness and oceanic location<sup>4,5,6</sup>, of islands. Island studies have tended to emphasize weakness in comparison with continental countries. However, there is now a shift to considering island properties themselves, which have superior qualities such as beautiful nature as a tourism source, large exclusive economic zones, and as strategic points for marine transportation<sup>7,8,9</sup>. Infrastructure vulnerability is being reduced through development of

micro-grid systems<sup>10</sup>. Some islands such as El Hierro in Spain, Samso in Denmark, and Bonaire in the Netherlands are trying to realize sustainable futures by promoting green energy; island study is growing as a research field of sustainable societies<sup>11,12,13</sup>. Thus, in this work, island energy security is considered by comparative study.

## 2. Overview of Okinawa Prefecture and the State of Hawaii

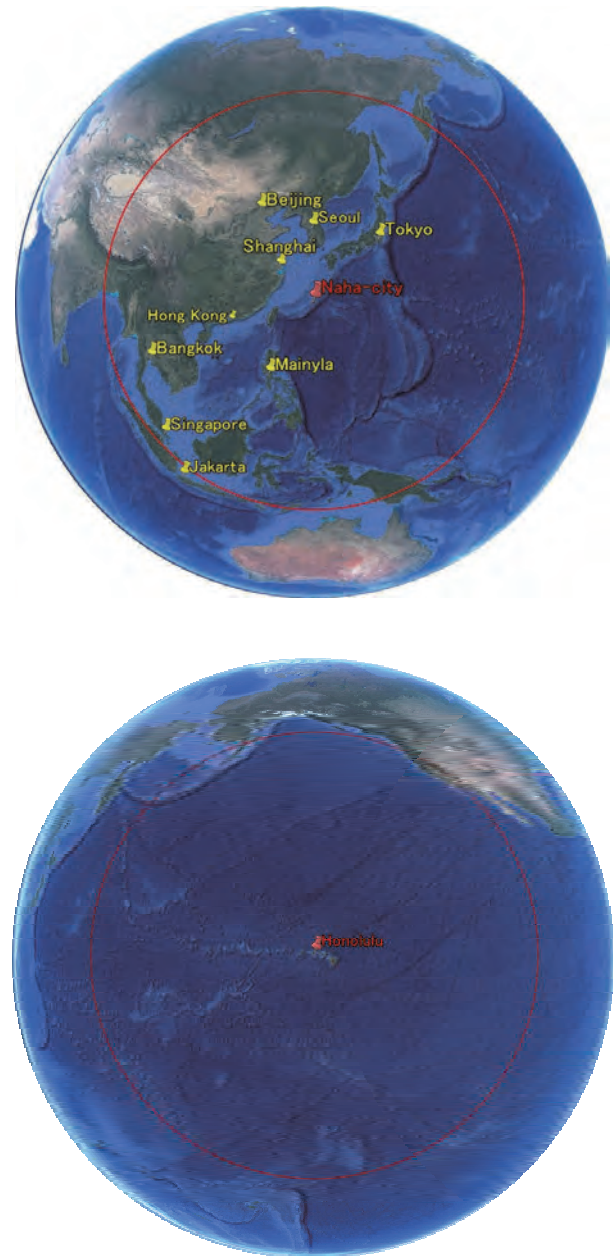
Firstly, we defined an island. According to the literature, an island is any area of land smaller than a continent and entirely surrounded by water<sup>14</sup>. The ten largest islands are Greenland, New Guinea, Borneo, Madagascar, Baffin, Sumatra, Japan's Honshu, Victoria, Great Britain, and Ellesmere. Being an island does not always involve a small economy. For example Japan, the third largest economy in the world in terms of GDP, is a typical island country. In this research, we defined "small islands" as those with a total population of under 1.5 million<sup>15</sup>. Therefore, Okinawa prefecture in Japan and the State of Hawaii in the USA were selected as small islands for comparative study because of their similar properties.

Figure 1 and Table I show the position and basic statistics of both islands<sup>16</sup>. Okinawa prefecture is located

in the south of Japan and is its westernmost prefecture. It is comprised of 363 islands in the East China Sea and Pacific Ocean, which are a strategic point of ocean transportation on a principal shipping lane<sup>17,18</sup>. The seat of prefectural government is at Naha-city on Okinawa Island. The annual number of tourists is over 7.16 million and continues to increase<sup>19</sup>. The Köppen-Geiger climate classification is warm and wet (Cfa) and subtropical (Af)<sup>20</sup>. Okinawa Island is Cfa and Yaeyama Islands are Af. Although Cfa cannot uniformly describe the climate as it covers a wide range from the subtropics to the subarctic, annual rainfall generally peaks in summer. Annual rainfall in Af is heavy because it is constantly affected by the intertropical convergence zone. Temperature is relatively high with a small annual range. Humidity is also high due to large amounts of evaporation. Average daily hours of sunlight are low compared with a high-latitude region, due to increased cloud cover. Cumulonimbus cloud develops in the ocean during the day. The island is often hit with a heavy rain gust known as a squall. The marine climate provides low morning temperatures. Diurnal temperature range is relatively small; temperatures are high throughout. Snowfall has not been observed. The number of typhoons per year is the greatest by far compared to the rest of the group of Japanese islands<sup>21</sup>.

The State of Hawaii is comprised of the islands of Hawaii, Maui, Oahu, Kauai, Molokai, Lanai, Niihau, Kaho'olawe and over 100 other small islands located in the center of the Pacific Ocean. The capital is Honolulu on Oahu Island. It was the last state to join the USA, in 1959<sup>22</sup>. The state is located to the southwest of the USA, the northeast of Australia. Since their natural landscapes are diverse, and they enjoy a warm tropical climate, abundant public beaches, and active volcanoes, the islands attract much attention from tourists, surfers, biologists and volcanologists. As a result of its presence in the center of the Pacific Ocean, Hawaii has been heavily influenced by both North America and Asia. The climate classification is tropical monsoon (Am), Af and Cfa<sup>23</sup>. Since the trade winds from the east blow throughout the year, temperature and humidity are not high. Maximum diurnal temperature during summer is

about 31 °C, and the lowest temperature at night is about 24 °C. Diurnal temperature during winter is 28 °C. During the night the temperature tends not to drop below about 18 °C in the lowlands. However, there is snow cover in winter at high altitudes, such as at Mauna Kea and Mauna Loa on Hawaii island. In the Haleakala Mountains, snowfall is rare. On most of the Hawaiian islands there are two seasons of six months: rainy (May to October) and dry (October to May)<sup>24</sup>.



**Fig. 1.** Position of (a) Okinawa and (b) Hawaii islands. Red circle shows diameter of 8000 km centering each prefectural capital and yellow points indicate major cities. © 2016 Google.

**Table I.** Basic statistics of Okinawa prefecture and the state of Hawaii in 2014

	Okinawa prefecture	State of Hawaii
Home country	Japan	USA
Population	1 429 529	1 419 561
Area (km <sup>2</sup> )	2281	16 634
Population density(/km <sup>2</sup> )	627	72
Köppen-Geiger climate classification	Af, Cfa	Am, Af, Cfa
Major sources of income	Tourism	Tourism

### 3. Current energy situation in Okinawa Prefecture and the State of Hawaii

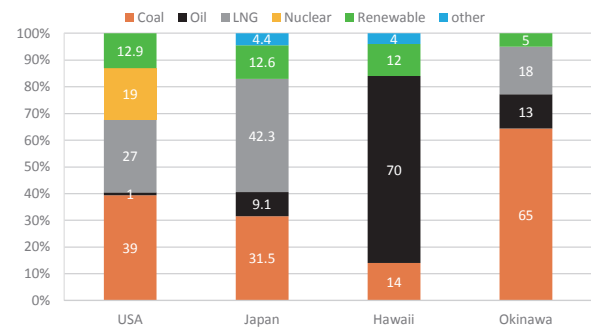
**Figure 2** and **Table II** show the ratio of electricity generation capacity in Okinawa prefecture and the state of Hawaii, compared to the averages of Japan and USA in 2014<sup>25,26)</sup>, and parameters of electric power generation on both islands, respectively<sup>27,28,29)</sup>.

The Okinawa Electric Power Company covers only Okinawa prefecture, the smallest supply region in Japan. Electric power generation was 8643 GWh in 2014. The ratio is coal: 65%, oil: 13%, liquefied natural gas (LNG): 18%, and others: 5%. There are no nuclear power plants; however the long-term business plan mentions the possibility of installation of a compact plant<sup>30)</sup> and the environmental action report in 2012 gathered information related to nuclear power<sup>31)</sup>. An LNG electric power generation plant has been in operation at Nakagusuku village since 2013. As the power generation facilities of Okinawa Electric Power Company are thermal systems, their business structure is subject to increasing fossil fuel prices. However, fuel is tax exempt following the *Act on Special Measures for the Promotion and Development of Okinawa*<sup>32)</sup>. Okinawa prefectural government developed the *Okinawa Energy Vision* to address concerns about their high dependency on fossil fuels<sup>33)</sup>, after which the *Okinawa Energy Vision Action Plan* was formulated<sup>34,35)</sup>. The aim of this scheme is to ensure that fossil fuel dependency is reduced and the ratio of electric power generation by LNG and renewable energy is brought to the same level as the rest of Japan by 2020. Reflecting the impact of the earthquake in 2011, disaster prevention and mitigation aspects have also been added. In addition, model simulations of renewable energy are being voluntarily adopted: correspondence of energy supply and demand (Scenario I), and active promotion of renewable energy (Scenario II). If a large amount of renewable energy is installed on the existing grid, adverse effects will include lack of adjusting frequency, system stabilization, surplus electric power, and voltage fluctuation. The simulations assume that these problems are completely resolved. In Scenario II (2030), the proportion of wave power and ocean thermal energy conversion is second only to wind and solar power generation. In the future, research will be actively carried out in the field. Based on these facts, an “Action Plan” has been developed.

On the other hand, Hawaii Electric Power Company (HECO) covers almost all of the state of Hawaii. Kauai Island Utility Cooperative (KIUC) supplies electricity on Kauai Island. Electric power generation in the state of Hawaii was 9421 GWh in 2014. The ratio of electric power generation is coal: 14%, oil: 70%, biomass: 3%, geothermal power: 3%, wind: 5%, hydropower: 1%, solar: 0.2%, and others: 4%. There is no nuclear power plant. Annual CO<sub>2</sub> emissions from electricity are almost equal to those of Okinawa prefecture but total CO<sub>2</sub> from all sources is higher in Hawaii. The electricity rate of the

energy end use sector is relatively low and transportation rate is high<sup>36)</sup>. New technology, including smart grids, has been actively deployed for them with support from Japan<sup>37)</sup>. Total electric power generation is greater than Okinawa prefecture, and power generation by renewable energy is nearly six times that of Okinawa prefecture. Although as in Okinawa prefecture, almost all fossil fuel is imported, oil dependency is higher in Hawaii and their average electricity rate is the highest in the USA (**Table II**). This may be because there is no tax exemption for fossil fuels. However, the state government and the power company developed the Hawaii Clean Energy Initiative (HCEI) in 2008 from Renewable Portfolio Standards (RPS) and Energy Efficiency Portfolio Standards (EPS)<sup>38)</sup>. The aim of this scheme is to provide 70% of energy demand from clean energy by 2030 through introduction of energy-saving measures, (30%) and local renewable energy technology (40%)<sup>39,40)</sup>. While the scheme is currently going well, it will be difficult to achieve the aims whilst maintaining a stable supply and low costs.

While many other parts of the United States have set



**Fig. 2.** Ratio of electric-generating capacity in Okinawa prefecture, the state of Hawaii, and the averages of Japan and the USA in 2014.

**Table II.** Parameters of electric power generation in Okinawa prefecture and the state of Hawaii in 2014.

Parameters	Okinawa prefecture	State of Hawaii
Annual electric power generation (GWh)	8643	9421
Average electricity rate (\$/kWh)	0.22 (JPN: 0.26)	0.37 (USA: 0.10)
Power generation by renewable energy (GWh)	345	1988
Amount of CO <sub>2</sub> emissions by electricity (million tons)	7.236	7.313
Total amount of CO <sub>2</sub> emissions (million tons)	12.4	18.0



the RPS, the state of Hawaii presents a relatively ambitious aim in this regard<sup>41)</sup>. In 2014, power generation from renewable energy in Hawaii was 1988 GWh (21% of the total). If power generation remains constant, then to achieve the RPS by 2030, it will be necessary to utilize renewable energy for a further 20% of, or double, the power generation. Use of renewable energy has increased steadily since 2008; it has already achieved the 2015 target. Thus, progress towards achieving the target for 2020 is positive. Improvement of energy efficiency plays a major role. In order to promote energy efficiency there is an energy efficiency department of the Hawaii Industrial Economic Development Tourism Bureau, which is promoting an energy-saving program.

In addition, in 2013, the government of Hawaii published the Energy Policy Directives which consist of the following five principles:

1. *Diversifying our energy portfolio*
2. *Connecting and modernizing our grids*
3. *Balancing technical, economic, environmental, and cultural considerations*
4. *Leveraging our position as an innovation test bed*
5. *Creating an efficient marketplace that benefits producers and consumers*

(From *Energy Policy Directives*<sup>42)</sup>)

Principle 1 suggests the possibility of accepting inexpensive natural gas from the USA mainland. In fact, HECO has reportedly agreed to the initiative to convert to power generation from natural gas instead of petroleum<sup>43)</sup>. Principle 4 is interesting in that it refers to the advantages of an island economy.

Scores on three factors related to energy security are summarized in **Table III**.

**Table III.** Evaluation of present energy security on Okinawa prefecture and the State of Hawaii.

	Okinawa prefecture	State of Hawaii
Stability	C	C
Environment	B	C
Cost	A	C

A: Good, B: Average, C: Weak

Stability scores are C (weak) because of both islands' high reliance on fossil fuels, as shown in **Fig. 2**. Scores for the environment for Okinawa prefecture and the State of Hawaii are B (average) and C, respectively. This is because the total amount of CO<sub>2</sub> emissions in Okinawa prefecture are relatively low as indicated in **Table II**. The scores for cost in Okinawa prefecture and the state of Hawaii are A and C respectively, because Hawaii heavily depends on oil thermal power generation (a high cost method). Okinawa prefecture has enjoyed special treatment regarding tax on fossil fuels from its home country<sup>32)</sup>.

## 4. Consideration of energy best-mix in Okinawa Prefecture and the State of Hawaii

By using data on the energy situation and features of power generation methods, the energy best-mix in Okinawa prefecture and the State of Hawaii was examined from the viewpoint of the islands' energy security. The ideal construction of power generation methods includes diversification of power sources and methods, which means dispersion of risk associated with energy supply, environmental conservation, and cost. Therefore, firstly, the basic specifications of each power generation method are reviewed for each island.

### 4.1. Review of power generation methods

**Table IV** shows a comparison of electric power generation methods<sup>44,45)</sup>.

Nuclear power generation uses a rotating turbine powered by steam generated from a nuclear reaction. The supply of fuel is an international commitment. It is possible to provide a stable, large capacity energy source but output adjustment is difficult, so nuclear power is used as the base power supply. It requires seawater as coolant, so the location for nuclear power plants is limited to the coast. Although running costs are low, it is widely accepted that were an accident to occur, compensation costs would be huge. Environmentally, nuclear power generation is favorable because it does not emit CO<sub>2</sub>, although an accident would have very serious impacts on ecosystems in terms of radiation. In addition, radioactive waste must be stored for several million years, necessitating geological disposal.

Thermal power generation is the typical method for fixing supply. Electricity is generated by a rotating turbine driven by the heat of burning fuel. Fuel types are coal, oil, and LNG. Location is limited to the coast because fuel upload by tanker is necessary. Each fuel has different features. Thermal power generation can provide a stable supply in a compact space. Power conditioning is relatively wide so it can be used as a middle supply source. Coal is used as a base-load supply method. Whereas cost is generally low, it does depend on fuel prices so the value can fluctuate<sup>46)</sup>. Electricity rates have been greatly affected by changes in the oil price and exchange rate. Undeveloped fuels such as the oil sands of Canada, shale gas, oil shale, and methane hydrate are not yet viable<sup>47)</sup>. Extraction costs must be reduced before methane hydrate can be used. In terms of the environment, greenhouse gases and toxic gases such as CO<sub>2</sub> and NO<sub>x</sub> are emitted. As mentioned above, this method has thus far been both islands' main power source.

Hydropower uses the potential energy of water. Since the output adjustment capability is excellent, regulating ponds, reservoir hydropower, and pumped storage hydroelectric power have all been used as peak power supplies, although the cost is higher than nuclear and thermal power generation. Environmental impacts include the destruction of part of the ecosystem of a

basin. Use of a dam requires a large reservoir, and so location depends on terrain. Hydropower is widely used in Hawaii as it is mountainous, but installation in Okinawa Prefecture is difficult because of the topography.

Solar power generation uses photovoltaic cells to generate power. As generation can be performed directly onsite, there are no transmission costs. However, in the case of mega solar panel farms, a supply center and distribution are required. Supply is unstable and dependent on the weather. In terms of cost, the current power generation unit price is in excess of 40 yen per kW. It does not emit CO<sub>2</sub> during power generation. Landscape destruction and land occupation can result from installation of solar panels. Location is unlimited and as such solar power is one of the most popular renewable power generation methods.

Wind utilizes the potential energy regeneration of the wind and is inexhaustible. Power generated must be distributed from supply locations. Supply is extremely unstable; wind has great seasonal variation. Generally, this method generates more power in the winter than the summer, which does not match the seasonal variation of electricity demand. Installation is limited to mountainous and certain coastal areas, making it difficult to incorporate into the power supply plan. In areas with an average wind speed of 5 m/s, it is possible to generate electricity at an affordable price of 10–14 yen/kWh. Wind power does not emit greenhouse gases, but noise has an unexpectedly large impact on the environment, and has been reported as a health hazard to humans<sup>48)</sup>. Thus, offshore wind power generation has attracted attention. However, it causes ecological destruction and its impact on fisheries is a concern. In addition, there is also landscape destruction. In Hawaii, wind power generation was actively introduced in the same way as solar power in

mountainous areas and has been promoted in coastal areas. In Okinawa Prefecture, retractable wind power in outlying areas has been successful in suppressing the damage caused by typhoons<sup>49,50)</sup>.

Geothermal power uses underground steam as an energy source. It is highly stable and so can be used as the base power supply. The power generation unit price is relatively cheap, but location is limited to areas of geothermal activity. Therefore, power generation capabilities are limited. In Hachijo Island in Japan, geothermal energy has become an effective power source<sup>51)</sup>. Although it does not emit CO<sub>2</sub>, air and water pollution caused by toxic substances are a concern. In the state of Hawaii, which has many volcanoes, development is progressing. On the other hand, in Okinawa Prefecture it is impossible to install due to geographical conditions.

Ocean thermal energy conversion utilizes the temperature difference between deep and shallow water. Surface sea water temperature should be higher than 25 °C. The cost is rather high at this stage. The ecosystem may be negatively affected by changing the spatial distribution of sea temperature. It is a promising future clean energy source in both Hawaii and Okinawa Prefecture due to their locations, and may become a leading power generation source. Demonstration tests have been carried out on both islands.

Biomass energy uses organic matter as fuel. Although CO<sub>2</sub> is generated by burning fuel, the plants comprising the biomass originally absorbed that CO<sub>2</sub> during growth, which offsets the emissions to a certain extent. There are no fundamental constraints on location. The random nature and seasonal fluctuations in the fuel source impact stability. The unit cost has decreased to a practical level. Toxic gases such as methane and nitrogen oxides can be released. If commitments are made to technically address environmental aspects, biomass has the potential to be an

**Table IV.** Comparison of electric power generation methods.

Method of power supply		Site location	Cost (Yen/kWh)	CO <sub>2</sub> emission (g/kWh)	Power conditioning	Effect on environment
Nuclear		Coast	4.8 – 6.2	22 – 25	Difficult to control	Radioactive pollution
Thermal	LNG	Coast	5.8 - 7.1	608	Controllable	CO <sub>2</sub> emission
	LNG combined	Coast	N/A	519	Controllable	
	Oil	Coast	10.0 – 17.3	742	Controllable	
	Coal	Coast	5.9 - 6.5	975	Difficult to control	
Hydro	Water pumping	Upper reaches	8.2 – 13.3	11	Flexibly controllable	Disruption of ecosystem
	Water reservoir	Upper reaches				
	Run-of-river	Upper reaches				
Solar	Personal use	In the sun	46	53	No need	Disruption of landscape
	Mega-solar	In the sun				Possession of land
Wind		Wind speed > 5m/s	10 – 14	29	No need	Noise
Micro-Hydro		River and water channel	N/A	N/A	Flexibly controllable	Disruption of landscape
Geothermal		Geothermal district	8 – 22	15	Difficult to control	Air and water pollution
Ocean thermal energy conversion		Ocean temperature on surface > 25 ° C	40 – 60	N/A	Difficult to control	Disruption of ecosystem
Biomass		No limit	11 – 40	N/A	Difficult to control	Methane, NO <sub>x</sub> emission
Waste		No limit	12	N/A	Difficult to control	Dioxin emission

influential power generation source in the islands.

Waste power generation, which burns waste to generate power, has no basic restrictions on location and can be utilized as the base power supply. Cost is low, and it is possible to carry out waste disposal at the same time. However, dioxin is discharged.

#### 4.2. Future energy scenario of Okinawa Prefecture and the State of Hawaii

A nuclear power plant should be considered since it has the lowest cost and CO<sub>2</sub> emissions of all the options. Okinawa Electric Power Company mentions nuclear power in their business plan but difficulties exist because of concerns about potential radioactive pollution resulting from an accident such as Fukushima or Chernobyl<sup>52)</sup>. The government of Hawaii has banned nuclear power plants by law<sup>53)</sup>. Therefore, nuclear power is not a realistic solution as a baseload power source for such a small island. Hence, Hawaii is forced to depend on thermal power generation as the supply source for base and middle loads. This is a common problem for islands; diversification of sources is needed. Increasing the ratio of LNG power generation is one promising way. Okinawa Electric Power Company and HECO have reportedly agreed to an initiative to convert to natural gas power generation from coal and oil<sup>54,55)</sup>. This improves economic and environmental aspects although investment in the facilities would still be needed.

Hydroelectric power generation performs well in terms of cost and CO<sub>2</sub> emissions, and its wide range of power conditioning. Okinawa prefecture and the state of Hawaii utilize hydroelectric power but cannot heavily rely on it because due to topography, there are no large rivers on either island. In Okinawa prefecture, pumped-storage power generation, a form of hydroelectric generation, is utilized, but a capacity deficit means that currently it must be combined with nuclear power. Consequently, wind power is suitable as the main clean energy because of its practical low cost. Nonetheless, the Okinawa energy policy indicates that the largest ratio of clean energy is currently solar power. The reason for this is unclear but it may be due to energy policies such as the feed-in-tariff (FIT), decoupling, net metering, and tax relief for solar power. Although these effectively provide incentives for the clean energy supplier, sustainability becomes a problem because it leads to excessive investment in solar power<sup>56)</sup>. Investment in an energy storage system will also be indispensable. Energy policy must focus on energy security, an aspect in which wind is also strong. In simulation results from Okinawa prefectural government, wind power is indicated as the most suitable clean energy<sup>35)</sup>.

Technical innovation and energy saving are important activities to consider with regards to energy security. Wave power generation and ocean thermal energy conversion are attracting much attention in both Okinawa prefecture and the State of Hawaii due to their oceanic and subtropical climates. Their governments have been

demonstrating its capability since 2012<sup>57,58)</sup>, although the cost is high relative to the other methods discussed in section 4.1. Thus cost reduction will be essential. In addition, Negawatt power is one solution for saving energy. This is a theoretical unit of power representing an amount of energy saved. The energy saved is a direct result of energy conservation or increased energy efficiency<sup>59)</sup>. Okinawa prefectural government and the State of Hawaii have not expressly mentioned the Negawatt; their plans rely on numerical goals.

#### 5. Conclusion

The energy security of Okinawa prefecture and the State of Hawaii were discussed through comparative study. Dependency on thermal power generation was over 80% because of certain characteristics that the islands possess, though the details are different. In Okinawa prefecture, the cost of their energy supply system is relatively low for an island although coal dependency is high. On the other hand, the power supply ratio of Hawaii depends heavily on oil and its cost is relatively high. From such a vulnerable position in terms of energy security, future plans that enhance clean energy options will be introduced. Some points included in their policies are as follows:

1. Okinawa energy vision action plan  
This deal aims to increase the ratio of power generation by LNG and renewable energy to the same level as the rest of Japan to reduce high dependency on coal.
2. Hawaii clean energy initiatives  
This aims for 70% of energy demand to be covered by clean energy. From this, 30% will come from saving energy, and 40% comes from use of renewable energy. Progress is occurring at a faster pace than originally expected. With this momentum, they are aiming to establish international status as a test bed of clean energy.

Policy orientations are different despite their similar properties as islands (chapter 2). In the medium and short term, the Okinawa energy vision action plan is better because it can fall back on the energy security of Japan. In the long term, Hawaii's clean energy initiatives might be better because investment in clean energy and energy saving would be actively carried out. However, at present, the immediate goal also includes practical aspects such as cost-performance, supply stability and fairness of obligation to obtain economic reliability.

As a result, from the viewpoint of energy security, we conclude that diversification of thermal power generation, innovation regarding clean energy and energy saving technology, and relationship with the home country are important key factors for island energy security.

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