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著者	kai Takami, Uemura Yoshimatsu, Kawamura Yosuke, Takahashi Takeshige, Hatate Yasuo, Yoshida Masahiro
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Energy system based on hydrodynamic power in Yakushima Island

Takami Kai^{*}, Yoshimitsu Uemura, Yosuke Kawamura, Takeshige Takahashi,
Yasuo Hatate and Masahiro Yoshida

*Department of Applied Chemistry and Chemical Engineering, Kagoshima University,
Korimoto 1-21-40, Kagoshima 890-0065, Japan*

* Corresponding author.
Takami Kai

Department of Applied Chemistry and Chemical Engineering
Kagoshima University
1-21-40 Korimoto, Kagoshima 890-0065, Japan

Tel +81 99 285 8361; fax +81 285 8361.
E-mail address: t.kai@cen.kagoshima-u.ac.jp (T. Kai).

Abstract

Yakushima Island was used as a model area where material recycling and indigenous energy systems would be realized based on the zero-emission concept in the near future. We evaluated the renewable energy resources to propose a regional energy system on this island. In this paper, the present energy demand and supply structure was quantitatively specified, and the water potential was evaluated. The energy system in Yakushima is unique, with hydroelectric power supplying about 30% of the total energy consumption mainly by commercial and residential sectors. However, petroleum remains the main source of primary energy for transportation, heating, and cooking. The hydroelectric power yielded on the island is sufficient to cover all the energy demands on the island. We found that fossil fuel energy in Yakushima could be substituted with hydroelectric energy without causing an impact on the environment.

Keywords: Hydropower; Water potential; Yakushima

1. Introduction

Yakushima is a circular island located in the ocean 60 km from the southernmost tip of Kyushu, Japan. Fig. 1 presents a map showing the location of Yakushima. The area is 505 km² with a population of 14,000. The annual precipitation in Yakushima is 10,000 mm in the mountainous area, and the average value is about 4500 mm. The altitude of the highest mountain on the island is 1935 m, and the average altitude is 600 m [1 and 2].

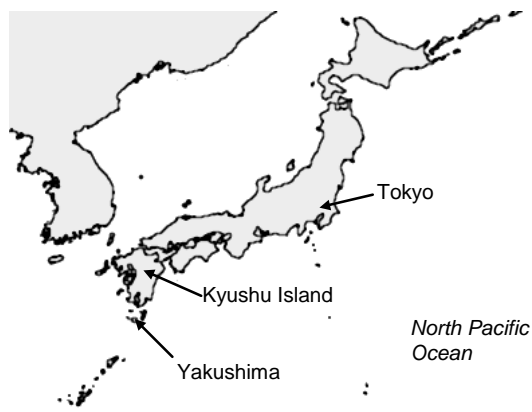


Fig. 1. Location of Yakushima island.

The island was added onto the World Natural Heritage List in 1993. The criteria are N-ii and N-iii. In the wide range of altitudes ranging from the coastline to the 2000 m-high mountains,

Yakushima exhibits a very rich floral zone with 1300 species and subspecies of plants, including some species unique to Yakushima [1 and 2]. The climate varies with an increase of the altitude from subtropical to subarctic zones. This change causes great diversity in species. There are natural forests of cedars, which are several thousand years old, rare Yakushima rhododendrons, and many other plants. The island contains many valuable species. The most famous cedar is a tree called the Jomon-sugi. It is considered to be 7200 years old, and is known to be the oldest plant in the world [1].

Yakushima has been previously studied as a model area where material-recycling and regional energy systems will be realized based on the zero-emission concept [3 and 4]. Since the island is a steep alpine club with large amounts of water, the potential of hydroelectric power is considered to be sufficient to realize the zero-emission concept. Actually, the electric power consumed on the island has been supplied mainly from hydroelectric power. Therefore, this has made the energy strategy of Yakushima different from that of other areas in Japan.

However, the island also still depends on fossil fuels imported from outside sources. Many plans concerning the reduction of the consumption of fossil fuels have been proposed. The production of bio-diesel fuel from used vegetable oils is one of the practical applications that have been considered. Fifteen automobiles that are part of the public office fleet use this bio-diesel fuel, but it is difficult to expand this fuel, because the amount of product is limited by the consumption of the vegetable oils on the island. Although realistic plans have never been implemented, Yakushima has the highest potential in Japan to realize a renewable energy system that is independent of fossil fuels.

Since Yakushima is an island, it is easy to keep track of and

investigate the amount of import and export of every material, and energy demand and supply. The objective of the present study is to quantitatively investigate the current energy demand and supply in Yakushima. We also evaluate the hydropower potential, and the possibility of substituting fossil fuels with hydroelectric power.

2. Energy demand and supply

The energy consumed in Yakushima is based on electric power, liquefied petroleum gas (LPG), gasoline, kerosene, diesel oil, and heavy oil. Although a small amount of firewood is also used, it is excluded from the present analysis. As it is necessary to inspect a hydroelectric power plant periodically, a portion of the power supply was sometimes displaced by power supplied by a thermal power plant using heavy oil. Basically, the electric power used on this island has been fully covered by hydroelectric power in recent years. The height of standing water (referred to as "water-head") is high due to the unique geographical features of the island, as described above. Fig. 2 shows the ratio of each energy source used in Yakushima based on the previous study [3]. About 30% of the energy depends on renewable energy, namely hydroelectric power. Although the development and introduction of hydropower generation are encouraged [5], the average value of that in Japan is about 3%. This result shows that the energy system in Yakushima largely relies on natural resources.

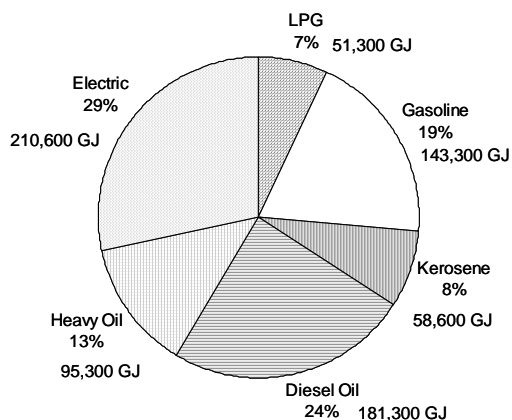


Fig. 2. Structure of energy supply in Yakushima.

A private company, Yakushima Denko Co. Ltd., owns the hydroelectric generation facilities on the island, and consumes most of the generated electric energy in the production of silicon carbide. The company also sells some portions of its energy generation to commercial and residential sectors on the island. Since a large amount of energy is consumed by this company, Fig. 2 excludes the company's consumption. There are no other large manufacturers in Yakushima, and energy consumption by the commercial and residential sectors corresponds to the energy supply shown in Fig. 2.

LPG is imported from outside sources. The main use of LPG is fuel for gas ranges for cooking. In addition, LPG is burned in order to heat hot water used in kitchens and bathrooms. In Japan, city gas networks have been developed for most parts of the country. City gas, which is mainly composed of methane, is usually used for cooking and heating bathwater in each home. In Yakushima, however, pipeline networks have not been developed, and cylinders of LPG are distributed to each consumer.

Gasoline and diesel oil are sold at gas stations. There are 13 gas stations in Yakushima. These fuels are used for transportation.

Since fuel must be transported to the island, and this is costly, the price of these fuels are about 30% higher than the average price in Japan. The classification of diesel oil in Fig. 2 contains the consumption of LPG by taxis. There are about 50 taxis on the island, and they use LPG as fuel.

Kerosene is used as a fuel for stoves and bathwater heaters. Since kerosene is also distributed by dealers to each consumer, there is little difference in convenience for consumers between kerosene and LPG. The price of kerosene is about half of that of LPG, based on the heating value. Therefore, the use of LPG for space heating is insignificant. Kerosene is also preferable for bathwater heating because of its low cost.

Heavy oil is used for heating bathwater and reheating hot spring water in accommodation. It is also used to fuel fishing boats and ferryboats, and is consumed in agricultural and industrial sessions.

The consumption of diesel oil is larger than that of gasoline on this island. This tendency is different from the average consumption pattern in Japan. Although the consumption ratio of diesel oil to gasoline is about 0.73 in Japan, in Yakushima, it is 1.27. In Yakushima, the percentage of population employed in the agriculture and construction sectors is much larger than that of the average value in Japan (Table 1). The main fuel for these vehicles is diesel oil. On the other hand, the consumption of gasoline used for commuting and for leisure is limited because of the small area of the island. Therefore, the consumption of diesel oil is larger than that of gasoline. Another reason for this is that the prices of fuels are higher than those in other areas of Japan, as mentioned above, and diesel cars are preferred because of its lower price.

Table 1. Employed population in agriculture and construction sectors

Sector	Yakushima	Japan
Agriculture and forestry	11.0 %	4.6 %
Construction	15.5 %	10.0 %

Since tourism is one of the most important industries in Yakushima, we evaluated energy consumption by tourists. Fig. 3 shows the increase in the number of visitors to Yakushima [6]. The number of visitors has gradually increased, and doubled from 1988 to 2000. There are no statistical data on the number of tourists, and the ratio of tourists among visitors to the island is not clear. The number of tourists in Fig. 3 is supposed to be obtained by multiplying the number of visitors by a constant. According to this estimation, about 160,000 tourists visited the island over a period of several years. We consider this value to be an underestimation, and estimate that 80% of the visitors to the island are tourists.

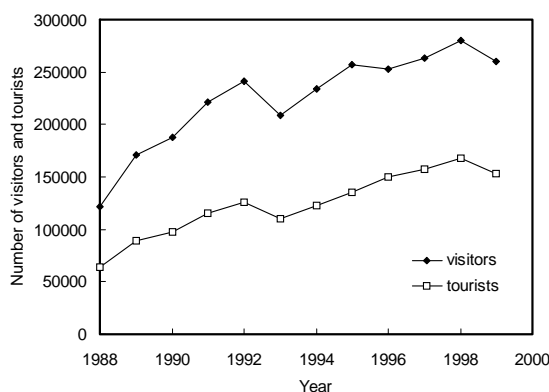


Fig. 3. Change in number of visitors and tourists. The increase in tourism presents a dilemma. Although it is

economically beneficial to the island, an increase in tourists means an increase in fossil-energy consumption. In addition, since 6000 tourists hike and backpack on the island's mountains every year, they might cause an impact on the environment. Fig. 4 shows the change in the capacity of hotel accommodation over the years [6]. Energy consumption and the yield of waste materials by tourists are considered to increase with increasing accommodation capacity.

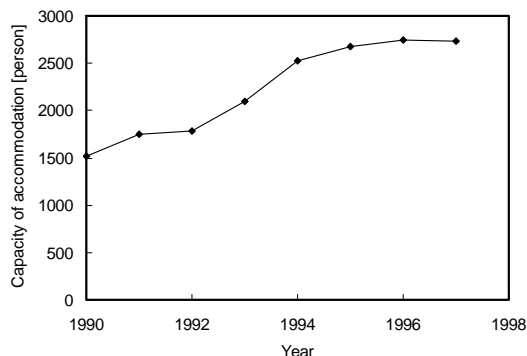


Fig. 4. Change in capacity of accommodation in Yakushima.

We investigated the energy consumption in the types of accommodation available on the island based on the number of tourists. There are many types of hotels and lodging houses on the island. The biggest part of energy consumption in hotels comes from heating bathwater and reheating hot spring water. In addition, the guests use electricity for air-conditioning and electrical utilities. We summarized the energy consumption based on the previous data [3] for these items. The energy used for transportation, including buses, rental cars, taxis, and minivans was calculated using the data of number of these vehicles and their mileages. The usage of rental cars increased three times in the period from 1992 to 2001, and the usage of buses was doubled during this period [6]. Therefore, the consumption of fossil fuels in the tourism section showed a large increase. As a result, the sum obtained of the energy consumption by tourism was 110 GJ. This value is about 14.8% of the total energy consumption on the island.

3. Potential energy of hydropower

Yakushima has a sufficient amount of hydroelectric potential. There are four hydroelectric facilities, three of which are located on the Anbo river (see Fig. 5). The amount of power generated by these three power plants is over 99% of the total power generated. Two of the main plants generate power using about 300 m of water-head, and their capacities are 23.2 and 32 MW, respectively. The power plant located the furthest downstream is situated underground, 170 m from the mountain surface. This site is slightly above sea level. There is no environmental noise on the surface above this site.

According to research conducted by the Ministry of the Environment (a Japanese governmental agency) [7], there are 36 sites that are candidates for relatively large hydropower plants in Yakushima. Many mini- and microplants are likely to be installed. The total potential of hydroelectric power is estimated at 254 MW. Fig. 6 shows the potential hydropower and the generation by the existing hydroelectric facilities. The potential hydropower is about three times that of the generation produced by the existing hydroelectric plants. The total present value of the generating capacity, including the consumption by the Yakushima Denko Co.

Ltd., is about 361 GWh. However, the consumption of electric energy in the residential sector is 58 GWh, and is only 5% of the water potential of this island.

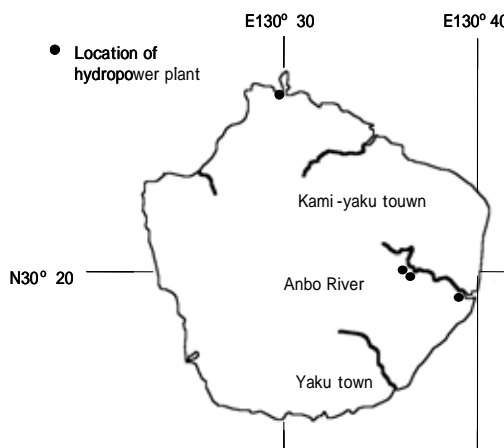


Fig. 5. Location of hydroelectric plants in Yakushima.

It is possible that in the near future, we will be less dependent on fossil fuel. We evaluated the substitution of fossil fuels with electric power. If fossil fuels were to be displaced by the same energy as electric power, it would require 530,000 GJ (147 GWh). This value was calculated based on the data given in Fig. 2. Namely, a hydropower plant with a capacity of 22 MW will be required when it is in operation at 75% capacity. The scale of this new plant is smaller than that of the existing plant. Generally, electric energy is used more efficiently than fossil fuels. Therefore, the amount of required electric power, as obtained above, would be reduced. We estimated the required power generation based on substituting it with presently existing technology using electric energy, by considering the efficiencies of devices using electricity and fossil fuels.

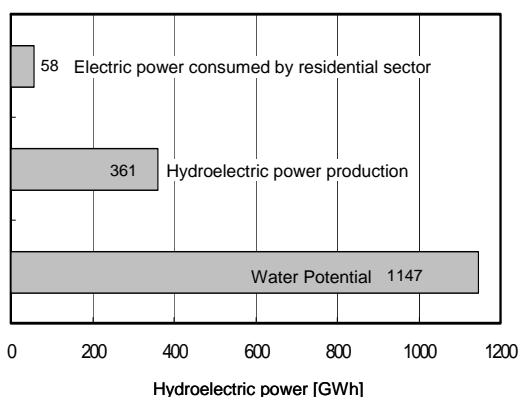


Fig. 6. Hydroelectric power production by existing plants and water potential.

The heat efficiency of a gas range is about 40%. By assuming that the efficiency of an induction-heating cooker is 80%, the energy of LPG can be substituted by 50% of electric energy. The energy supply from LPG, 51,300 GJ, shown in Fig. 2, can be displaced by 25,600 GJ of electric energy.

In residences, kerosene is mainly used for oil stoves and bathwater heating. The ratio of these items is assumed to be 1:9. The apparent efficiency of an air-conditioner is 300%, whereas the efficiency of an oil stove is almost 100%. Assuming the

efficiency of heating water by kerosene is 80% and that of electrical heating is 100%, we can conclude that the energy supply from kerosene, 58,600 GJ, given in Fig. 2, can be displaced by 44,100 GJ of electric energy.

We studied substitution by an electric automobile because it is considered to be most efficient in Yakushima. This type of car has already been marketed, and is presently being used as public office fleets in Yaku-town on the island. However, the use of this type of car is a trade-off, because the price of the car is twice that of the car that uses gasoline. In addition, exchanging the batteries on this car is costly. Therefore, at this stage, it is not realistic to expect the inhabitants of Yakushima to purchase electric automobiles. In this paper, however, the energy consumption of an electric automobile was compared with that of a gasoline car of the same model. The gasoline consumption of the car was 14.4 km/l when it was measured based on the Japanese standard 10–15 mode measurement. The efficiency of the electric version of the same type of car is calculated based on the available data [8] to be 5.5 km/kWh. In this estimation, we assumed that the efficiency of charge and discharge is 70%. By displacing gasoline cars with electric cars, the energy consumption of gasoline in Fig. 2, 143,300 kJ, can be reduced to 38,000 kJ of electric energy. In the case of diesel cars, the energy consumption of 181,300 kJ can be reduced to 55,400 kJ.

Heavy oil is mainly used for heating water and as fuels for boats. About 50% of this oil is used as fuel for boats. Electric heaters are available in place of oil heaters for heating water. However, the efficiency for heating is assumed to be the same as with kerosene. A boat, which installs fuel cells in the megawatt range, will be developed in the near future [9]. We assume that the efficiency changes will range from 30% to 50% by installing fuel cells on boats. Consequently, it will become possible to displace heavy oil consumption of 95,300 by 74,500 kJ of electricity.

It has already been mentioned that a hydroelectric power plant of 22 MW is required for substituting fossil fuels with hydroelectric power. Considering the efficiency of energy consumption, however, we calculated that the required electrical energy would be 238,000 GJ when fossil fuels are substituted with electric energy. In this case, the hydroelectric power plant that has a capacity of 11 MW (in operation at 75% capacity) can cover these energy demands. The addition of a generator of capacity 11 MW is possible without the development of a new site. It would be possible to install an additional generator at the base of an existing station. Consequently, we can conclude that Yakushima possesses enough energy to substitute all energy demands by hydroelectric power, without impacting the environment on the island.

4. Shift into a hydrogen economy

One choice available for Yakushima is to abandon fossil fuels for hydroelectric power. Although several problems would still remain, it would be possible for the island to shift to a renewable-hydrogen economy [10]. A private company in Yakushima, Yakushima Denko Co .Ltd., has proposed to create a new model of a sustainable hydrogen society [11]. Iceland is now trying to shift into the world's first hydrogen society. In Iceland, the economically harnessable hydroelectric energy is almost 30 TWh/y, and geothermal energy is almost 200 TWh/y [9]. However, only a part of the energy has been harnessed out of the huge amount of potential energy sources. About 43% of the energy used in Iceland is still dependent on imported fossil fuels [9]. Although the scale of Yakushima is about 5% of Iceland (see Table 2), the energy yielded by a hydropower plant is enough to supply all the automobiles on the island, and it is possible to

realize a scaled down version of Iceland in Yakushima.

Table 2. Comparison of Yakushima with Iceland Image

	Yakushima	Iceland	Iceland/ Yakushima
Population	14,000	280,000	20
Area	505km ²	103,000km ²	204
Potential of hydro power	1.2 TWh	30 TWh	25
Potential of geothermal	-	20 TWh	
Total power generation	0.36 TWh	8.3 TWh	23
Consumption of electric energy by public sector	0.058 TWh	2.9 TWh	50

The electric automobile is most efficient in Yakushima, because electricity is first generated from hydropower plants. When we take a wide view of the situation, however, hydrogen system is advantageous for automobiles. A large investment has been made towards development of the system including automobiles. Therefore, the energy system based on hydrogen is a choice available for Yakushima. Hydrogen can be produced without exhausting CO₂ in Yakushima. Many automakers have been developing fuel cell automobiles. In addition, BMW has tested the car powered by liquid hydrogen and constructed a refueling robot system for liquid hydrogen at Munich Airport [12].

Two Japanese automakers, Toyota and Honda, released fuel cell cars into the market in 2002. The fuel consumption of the FCX (Honda) is about 95 km/kg-H₂ [13]. If we assume that the efficiency of the electrolysis of water is 50%, the price of the hydrogen generated by hydroelectric power in Yakushima can be calculated. When we estimated the cost required for driving 100 km based on the price of hydrogen and gasoline in Yakushima, it was found that for both cases, the costs are almost the same, about 900 yen. Judging from this estimation of running cost, a future car-system based on hydrogen can be realized in Yakushima. DaimlerChrysler has been developing NECAR (new electric car) new electric car powered by fuel cells since 1994, and introduced a bus powered by fuel cells, NEBUS (new electric Bus) in 1997 [14]. The operating range of the NEBUS is 250 km. The public buses in Yakushima are operated on the road along the coastline. Since the distance between two terminals is about 75 km, it would be sufficient to construct one hydrogen filling-station for public bus operation. For a future hydrogen society, several hydrogen filling-stations should be strategically located, based on detailed research.

5. Conclusions

Hydroelectric generation in Yakushima plays a very important role in the energy supply. The renewable energy used by the residential sector is about 30% of the total energy consumption. Tourism is a main industry in the island, and energy consumption by this sector is about 14.8%. To exclude fossil fuels from Yakushima, we estimated the required capacity of a hydroelectric plant, and determined that it would be sufficient to construct an additional generator with an 11 MW-capacity by considering the efficiency of energy consumption. This facility is small, and will not impact the environment. Yakushima is one of the most suitable areas in Japan for a hydrogen economy system to be realized in the future.

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