Potential of renewable energy sources and its applications in Yakushima Island

Renewable Energy 29 (2004) 581-591

Potential of renewable energy sources and its applications in Yakushima Island

Yoshimitsu Uemura*, Takami Kai, Rintarou Natori, Takeshige Takahashi, Yasuo Hatate and Masahiro Yoshida

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

* Corresponding author.
Yoshimitsu Uemura

Fax : +81 99 285 5895.
E-mail address: yuemura@cen.kagoshima-u.ac.jp (Y. Uemura).

Abstract

A study was carried out to see if the potential of renewable energy sources other than hy droelectric power, such as wind, photovoltaic, solar thermal, biomass and waste energy sources, can meet the current energy consumption in Yakushima. The current electricity consumption can be covered by wind and photovoltaic energy sources. The total potential of wind and photovoltaic energy sources is 5.4 times as much as the current electricity consumption. LP gas and kerosene can be replaced by solar thermal and biogas energy. The potential of plant biomass and municipal waste is not sufficient (approximately one third) to cover the rest of the fossil fuels (gasoline, diesel oil and heavy oil). Also, plant biomass and municipal waste must be converted into fluid form. This shortage can be covered by the po tential of wind and photovoltaic energy sources. We also investigated the possibility of tourism expansion using the potential of wind and photovoltaic energy sources. Taking into account three types of capacity (energy, accommodation and transportation), Yakushima can accept approximately four times as many tourists as the current number of tourists.

Keywords: Renewable energy potential; Tourism; Yakushima

1. Introduction

Yakushima Island, one of the World Natural Heritage sites, is located in the southern part of Japan. On this island, there have been several activities and research projects related to ecology and environmental preservation. There are two major reasons for such activities. Firstly, Yakushima is geologically isolated. This fact enables people to better understand flows of material, energy and money. Secondly, since Yakushima is one of the World Natural Heritage sites, Yakushima people are very aware of any activities related to ecology and environmental preservation such as zero-emission, which was proposed by Gunter Pauli [1]. Currently, the major energy source for electricity on Yakushima is hydroelectric. The amount of electricity consumed is 58,400 MWh/y (or 211,000 GJ/y). The rest of the energy consumed on the island is mainly fossil fuels including LP gas, kerosene, gasoline, diesel oil and heavy oil. The amount is 530,000 GJ/y. On this island, hydroelectric, wind, photovoltaic, solar thermal, biomass and waste energy sources are available as renewable energy sources. The potential of hydroelectric energy on Yakushima was estimated and discussed in a previous paper [2]. In this paper, a study was carried out to see if renewable energy sources other than hydroelectric power, such as wind, photovoltaic, solar thermal, biomass and waste energy sources, can cover the current energy consumption in Yakushima.

2. Potential of renewable energy sources in Yakushima

The potential of renewable energy in Yakushima was estimated in order to propose how to reorganize the current energy supply system in Yakushima and how to promote tourism, which is the most promising industry on the island. As renewable energy sources, wind, photovoltaic, solar thermal, biomass and waste energy sources were selected for this paper. Fig. 1 shows a map of Yakushima, whose upper half is called Kami-yaku-cho and whose lower half is called Yaku-cho. Miyano-ura is the capital town of Kami-yaku-cho; Ono-aida is the capital town of Yaku-cho. Miyano-ura, Anbo and Ono-aida are the most populated places on the island.

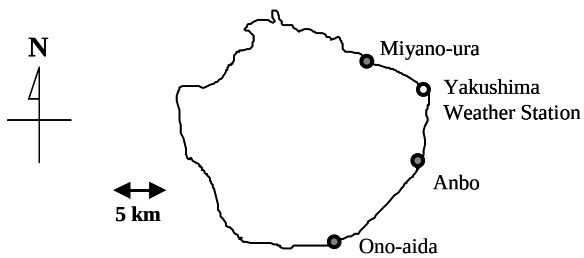

Fig. 1. A map of Yakushima.

2.1. Wind energy

The potential of wind energy in Yakushima was estimated as follows. The wind velocity data were supplied as a form of wind velocity distribution map [5], which was made based on the data on the NEDO home page [6]. The map is divided into 1 km^2-rectangular sections. Each section is characterized by the average wind velocity. It was assumed that five wind turbines of

500 kW are built in a rectangular section of 1 km^2 [3] that satisfies the four requirements listed below.

1. Square sections containing major prefectural roads (Nos. 77 and 78) or next to them.
2. Square sections whose average wind velocity is above 6–8 [m/s].
3. Square sections not containing human communities.
4. Square sections not containing nature preserve areas.

The first requirement was chosen because transporting a wind turbine requires well-constructed roads. The second was from consideration of the payback time [4]. The third was to avoid noise pollution. Fig. 2 shows a grid map for exhibiting the sections that satisfy the four requirements. Each square is 1 km×1 km. The thick-line squares exhibit the coast line of the island. The shadowed squares satisfy the four requirements. The number of sections satisfying the requirements was 56, and their total area was 45 km^2. All the sections were dropped in the 6–8 [m/s]-category. The result is summarized in Table 1.

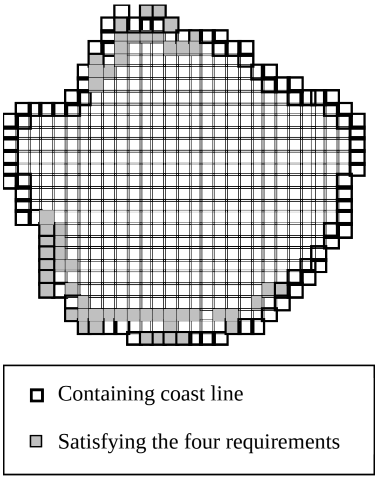

Fig. 2. A grid map of Yakushima for showing appropriate sites for wind power generation.

Table 1
Potential of wind energy for electricity production

Wind velocity range[m/s]	6-8
Average wind velocity[m/s]	7
Total area [km^2]	45
Number of wind turbines	225
Average power of one wind turbine [kW]	150
Electricity production by one wind turbine[MWh]	1,314
Total electricity production[MWh/y]	295,650 (=1,064,300 GJ/y)

2.2. Photovoltaic energy

The potential of photovoltaic energy was estimated using the data of solar radiation intensity at two sites, Yakushima Weather Station and Ono-aida [6]. The electricity production using a 1 kW solar battery was estimated as listed in Table 2. Using the intensity of solar radiation I (the second and fifth columns of Table 2), electricity production per month E was calculated using Eq. (1):

$$E = eD = \frac{PI}{P_0} K_1 D \qquad (1)$$

where e is the electricity production per day, D is the number of days per month, P is the solar battery capacity, P_0 is the standard solar radiation (1 kW/m^2), and K_1 is the loss coefficient of the solar battery. The solar battery capacity P applied was 1 kW. The loss coefficient was chosen as 0.69 [7]. As can be seen from the last line of Table 2, the electricity productions of a 1 kW-solar battery per year were 850 and 926 kWh at Yakushima Weather Station and Ono-aida, respectively. Taking these two values (850 and 926) as the representative ones for Kami-yaku-cho and Yaku-cho respectively, the potential of photovoltaic energy was estimated as shown in Table 3. It was assumed that each family build a 2.5 kW-solar battery on the house, and each company build a 10 kW-solar battery on the building.

Table 2
Estimating electricity production using solar battery of 1 kW

Site	Yakushima Weather Station			Ono-aida		
	I	e	E	I	e	E
Month	Intensity of solar radiation* [kWh/m^{2}d]	Electricity production per day [kWh/d]	Electricity production per month [kWh/month]	Intensity of solar radiation* [kWh/m^{2}d]	Electricity production per day [kWh/d]	Electricity production per month [kWh/month]
Jan	1.99	1.37	42.5	2.75	1.89	58.7
Feb	2.34	1.61	45.1	3.02	2.08	58.2
Mar	3.06	2.11	65.3	3.40	2.34	72.6
Apr	3.76	2.59	77.7	3.88	2.67	80.1
May	3.92	2.70	83.7	3.97	2.73	84.7
Jun	3.63	2.50	75.0	3.52	2.42	72.7
Jul	5.09	3.50	108.6	4.86	3.35	103.7
Aug	4.94	3.40	105.4	4.86	3.35	103.7
Sep	4.02	2.77	83.0	4.26	2.93	88.0
Oct	3.28	2.26	70.0	3.81	2.62	81.3
Nov	2.47	1.70	51.0	3.02	2.08	62.4
Dec	2.02	1.39	43.1	2.80	1.93	59.8
Sum			850.4			926.0

*: Inclination angle = 20 degrees, azimuth = 0 degree.

Table 3
Potential of photovoltaic energy

Town		Number of sites	Solar battery capacity [kW]	Annual electricity production per site [MWh/y]	Annual electricity production [MWh/y]
Kami-yaku	Households	3,104	2.5	2.13	6,599
	Companies	338	10	8.50	2,875
Yaku	Households	2,897	2.5	2.31	6,706
	Companies	315	10	9.26	2,917
Sum					19,097 (=68,700GJ/y)

2.3. Solar thermal energy

The potential of solar thermal energy was estimated using the data of solar radiation intensity at two sites, Yakushima Weather

Station and Ono-aida [6]. The collected thermal energy using a 1 m^2 solar panel was estimated as listed in Table 4. Using the intensity of solar radiation I (the second and fifth columns of Table 4), collected thermal energy per month Q was calculated using Eq. (2):

$$Q=3.6qD=3.6IK_2D \quad (2)$$

where q is the collected thermal energy per day, D is the number of days per month, and K_2 is the loss coefficient of the solar system. The loss coefficient was chosen as 0.4 [8]. As can be seen from the last line of Table 4, the collected amounts of thermal energy of a 1 m^2 collector per year were 1779 and 1937 MJ/m^2 at Yakushima Weather Station and Ono-aida, respectively. Taking these two values (1779 and 1937) as the representative ones for Kami-yaku-cho and Yaku-cho respectively, the potential of solar thermal energy was estimated as shown in Table 5. It was assumed that each family build a 6 m^2-solar panel on the house, and each company build an 18 m^2-solar panel on the building.

Table 4
Estimating collected thermal energy using a solar panel of 1 m^2

Site	Yakushima Weather Station			Ono-aida		
	I	*q*	*Q*	*I*	*q*	*Q*
Month	Intensity of solar radiation* [kWh/m^2d]	Collected thermal energy per day [MJ/m^2d]	Collected thermal energy per month [MJ/ m^2month]	Intensity of solar radiation* [kWh/m^2d]	Collected thermal energy per day [MJ/m^2d]	Collected thermal energy per month [MJ/ m^2month]
Jan	1.99	2.87	88.8	2.75	3.96	122.8
Feb	2.34	3.37	94.3	3.02	4.35	121.8
Mar	3.06	4.41	136.6	3.40	4.90	151.8
Apr	3.76	5.41	162.4	3.88	5.59	167.6
May	3.92	5.64	175.0	3.97	5.72	177.2
Jun	3.63	5.23	156.8	3.52	5.07	152.1
Jul	5.09	7.33	227.2	4.86	7.00	217.0
Aug	4.94	7.11	220.5	4.86	7.00	217.0
Sep	4.02	5.79	173.7	4.26	6.13	184.0
Oct	3.28	4.72	146.4	3.81	5.49	170.1
Nov	2.47	3.56	106.7	3.02	4.35	130.5
Dec	2.02	2.91	90.2	2.80	4.03	125.0
Sum			1778.7			1936.7

*: Inclination angle = 20 degrees, azimuth = 0 degree.

Table 5
Potential of solar thermal energy

Town		Number of sites	Collector area [m^2]	Collected thermal energy per site [GJ/y]	Collected thermal energy [GJ/y]
Kami-yaku	Households	3,104	6	10.7	33,127
	Companies	338	18	32.0	10,822
Yaku	Households	2,897	6	11.6	33,663
	Companies	315	18	34.9	10,981
Sum					88,593

2.4. Biomass and waste energy

The potential of biomass and waste energy was estimated using collected data on the amount of biomass and waste [5 and 9]. The result is summarized in Table 6.

Table 6
Biomass and waste energy

Item		Thermal energy [GJ/y]
Biogas from manure		10,500
Wood scraps	Lumbering	28,600
	Sawmill	17,700
	House destruction	57,200
Farm product waste		18,500
Municipal waste		22,000

3. Application of renewable energy

In Table 7, the potential of renewable energy sources is summarized. The energy sources are divided into three classes, i.e. electricity, fluid form and solid form energy sources. The use of solid form energy is very restricted in modern societies and industry. When we convert solid form energy into fluid form, the efficiency is said to be approximately 50%.

Table 7
Potential of renewable energy sources in Yakushima

Renewable energy source		Potential [GJ/y]
Electricity	Wind	1,064,300
	Photovoltaic	68,700
	Subtotal	*1,133,000*
Fluid form	Solar thermal	88,600
	Biogas	10,500
	Subtotal	*99,100*
Solid form	Wood scraps	103,500
	Farm product waste	18,500
	Municipal waste	22,000
	Subtotal	*144,000*
	[Subtotal, as fluid]	*[72,000]*
Total		1,376,100

3.1. Residential sector

In Table 8, the current energy consumption in Yakushima is summarized. Comparing the current energy consumption (Table 8) with the potential of renewable energy (Table 7), it is found that the current electricity consumption (210,600 GJ/y) could be covered by wind and photovoltaic energy sources (1,133,000 GJ/y). In fact, the sum of wind and solar energy sources is 5.4 times as much as the current electricity consumption in Yakushima. There are two things to be mentioned here. One is that wind and photovoltaic energy sources are considerably time- and weather-dependent. The percentage of wind and photovoltaic electricity that can be used in an island electrical grid is therefore restricted [10]. Very recently, however, the problem has begun to be solved by technological development [11]. Another is that the current electricity on Yakushima, hydroelectricity itself is a form of renewable energy. In other words, in this restricted case, there is no need to replace hydroelectricity by wind and solar electricity as long as the existing hydroelectric power plants work properly.

Table 8
Energy consumption in Yakushima

Energy type	Consumption [GJ/y]
Hydroelectricity	210,600
LP gas	51,300
Kerosene	58,600
Gasoline	143,300
Diesel oil	181,300
Heavy oil	95,300
Total	740,400

In the current energy system on Yakushima, fossil energy sources are divided into two according to consumption mode. The former (LP gas and kerosene) is for heating, hot water supply and baths for households and other buildings. The latter (gasoline, diesel oil and heavy oil) is for transportation and boilers. Since solar thermal and biogas energy are appropriate for heating, hot water supply and baths for households and other buildings, they may be replacements for LP gas and kerosene. Fortunately, the potential of solar thermal and biogas energy (99,100 GJ/y) is comparable with the consumed amounts of LP gas and kerosene (109,900 GJ/y).

Wood scraps, farm product waste and municipal waste can be used for transportation fuel and boiler fuel, if they are liquefied or gasified properly. The amount of fluid form energy from wood scraps, farm product waste and municipal waste (144,000 GJ/y) is estimated as 72,000 GJ/y, which is only 17% of the demand (419,900 GJ/y). This shortage (347,900 GJ/y) can be covered by electricity from wind and photovoltaic power (1,133,000 GJ/y). The supply form may be electricity itself or hydrogen. In the former case, electric cars are available; in the latter, hy drogen internal combustion cars or fuel cell cars can be used. It is noteworthy that hydrogen is a promising form of fuel for the near future [12].

3.2. Tourism

In Yakushima, people live on farming, fishing, construction and tourism. Farming and fishing are almost saturated. The construction industry may decline because government subsidies will shrink in the near future. Tourism is therefore the most promising industry in Yakushima. It is essential to evaluate how many tourists per annum are acceptable from the viewpoint of the available amount of renewable energy sources, i.e. wind and photovoltaic power (1,133,000 GJ/y), and compare the energy capacity with other factors, such as accommodation and transportation capacities.

As described in a previous paper [2], 260,000 people, including 160,000 tourists, visited the island annually over a period of several years. The tourists stay in Yakushima for 1.4 days on average. As a result, 110,000 GJ of energy was consumed annually by the tourists. This value is 15% of the total energy consumption (740,400 GJ/y) on the island. As discussed above, Yakushima has a wind and photovoltaic energy potential of 1,133,000 GJ/y as electricity. Yakushima's renewable energy potential is therefore at least ten times as much as the current consumption by tourism.

The accommodation capacity of Yakushima is 895,345 persons per year. Since 160,000 tourists stay in Yakushima for an average of 1.4 days, Yakushima's accommodation capacity is four times as much as the current load by tourism.

There are three types of transportation between the mainland and Yakushima, i.e. aircraft (seven return flights per day), jet foil (four round trips per day) and car ferry (one round trip per day). The total transportation capacity to Yakushima is 708,830 persons per year. Here it is assumed that the number of non-tourism passengers does not change. The factor of capacity to the current load by tourism, F, can be calculated as follows:

$$F \times \text{[number of tourists]} + \text{[number of non-tourism passengers]} = \text{[transportation capacity]}$$

$$F \times 160{,}000 + 100{,}000 = 708{,}830$$

$$\therefore F \approx 4$$

Yakushima's transportation capacity is therefore four times as much as the current load by tourism.

In short, taking into account three types of capacity (energy, accommodation and transportation), Yakushima can accept four times as many tourists as the current number of tourists. Practically, the factor "four" may be an overestimated value from the following considerations. One is that tourists to Yakushima are already saturated in two time periods (the Japanese long holiday in early May and the summer holiday). Another is that the tourists may have a preferable form of transportation. Some tourists do not like boarding aircrafts. Tourists from distant metropolitan areas such as Osaka or Tokyo may prefer aircrafts because Kagoshima Airport and the seaports for jet foil and car ferry are fairly distant (approximately 40 km), and public surface transportation service is insufficient. Nevertheless, Yakushima has extra capacity (maybe, a few times) for tourism. Since in the near future government subsidies for constructing roads, bridges and so forth will decrease, as mentioned above, tourism is supposed to become a very important in dustry for Yakushima. At that time, Yakushima people and local offices will have to deal with the expansion of tourism without incurring environmental damage. The point is how to utilize the huge potential of renewable energy sources on the island.

4. Conclusions

The current electricity consumption can be covered by wind and photovoltaic energy sources. In fact, the sum of wind and solar energy sources is 5.4 times as much as the current electricity consumption in Yakushima. Still, two things are noteworthy to mention. One is that wind and solar energy sources are considerably time- and weather-dependent, although improvements in technology have been clearing the problem to some extent. Another is that hydroelectricity itself is a form of renewable energy. In other words, in this restricted case, there is no need to replace hydroelectricity by wind and solar electricity as long as the existing hy droelectric power plants work properly.

LP gas and kerosene can be replaced by solar thermal and biogas energy. The potential of plant biomass and municipal waste is not sufficient (approximately one third) to cover the rest of the fossil fuels (gasoline, diesel oil and heavy oil). Also, plant biomass and municipal waste must be converted into fluid form. This shortage can be covered by the potential of wind and photovoltaic energy sources.

Taking into account three types of capacity (potential of renewable energy sources, accommodation and transportation), Yakushima can accept approximately four times as many tourists as the current number of tourists.

In this paper, the application of renewable energy sources to the current consumption system was proposed mainly on an annual-sum base. Sometimes, when one applies renewable energy sources to the current system, a time course profile of supply and demand should be taken into account from a practical point of view. Some kinds of renewable energy sources such as biomass are localized in Yakushima. Their transport must be taken into account in order to discuss them more practically. Solutions to these problems are now being studied.

Acknowledgements

We thank the Ministry of Education, Culture, Sports, Science and Technology, Japan for its financial support. We also thank Kami-yaku-cho Office, Yaku-cho Office and Yakushima Denko, Co. Ltd. for their help in collecting data.

References

[1] G. Pauli, Technological forecasting and assessment: The case of zero emissions. Technological Forecasting and Social Change 58 (1998), pp. 53–62.
[2] Kai T, Uemura Y, Yousuke K, Takahashi T, Hatate Y, Yoshida M. Energy system based on hydrodynamic power in Yakushima Island. Renewable Energy 2004;29:1–11.
[3] K. Seki and M. Ikeda, Q and A of wind power development. , Gakken-Sya, Tokyo (2002) [in Japanese] p. 39 .
[4] Y. Shimizu, Technology for wind power plant. , Power-Sya, Tokyo (1999) [in Japanese] p. 23 .
[5] Assessment report on regional new energy in Yaku-town [in Japanese]. Kagoshima: Yaku-town, p. 44, 1997.
[6] NEDO Home Page, http://www.nedo.go.jp/ [in Japanese, accessed January 2003].
[7] Y. Shimizu, Technology for renewable energy utilization. , Power-Sya, Tokyo (1999) [in Japanese] p. 75–76 .
[8] Solar System Promotion Institute Home Page, http:// www.solarsystemkyokai.or.jp/ [in Japanese, accessed January 2003].
[9] Report on working test project in the advanced area for preventing global warming [in Japanese]. Kagoshima: Kagoshima Prefecture, Yakushima Area, 2000.
[10] P. Poggi, G. Notton, J.L. Canaletti and A. Louche, Integration of large scale PV plants in an islander electrical grid case study of Corsica. In: (1997), pp. 1128–1131.
[11] A.A.M. Sayigh, Editor, Renewable energy, Pergamon, London (2002) pp. 199–252 .
[12] S. Dunn, Hydrogen futures: toward a sustainable energy system. International Journal of Hydrogen Energy 27 (2002), pp. 235–264.