Levelized Cost of Electricity for Wind-Solar Power Systems in Japan, a Review

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Abstract

To date no technical-economic-environmental review has been carried out on the use of hybrid wind-solar power plants in Japan. The study reported in this paper used HOMER software to analyze the electricity supply from renewable energy systems at 198 stations in Japan. The ranges of wind speed and solar radiation of the locations are 1.6-12 m/s and 2.723-5.435 kWh/m^2-day, respectively. The results show that the average, maximum and minimum use of renewable energy in Japan are 96.2%, 100% and 89%, respectively. Also, the average, maximum and minimum cost per kWh of energy are $ 0.434, $ 0.526, and $ 0.249, respectively. The cheapest wind turbine system (the cheapest renewable energy system), the cheapest solar system, the cheapest hybrid wind-solar system, and the most expensive hybrid system, have a price per kWh of energy $ 0.294, $ 0.349, $ 0.339 and $ 0.526, respectively. These systems are located at Fuji Mountain, Minamitorishima, Iwojima and Tokyo, respectively.

Keywords: Solar radiation, Wind speed, Battery, Converter, Rectifier, Japan

1. INTRODUCTION

Traditional energy such as coal, hydroelectric, nuclear, oil and natural gas are not responsive to the growth in energy demand. By 2040, energy demand is expected to increase by 30% as the demand and supply ratio increases [1]. Finite fossil fuel reserves and rising climate change concerns are driving the transition to renewable energy systems (RES), with government policies worldwide providing varying degrees of support. The total installed capacity of renewable electricity in the world was estimated to be 921 GW in 2016. Compared to 2015, it grew by 14% and the PV capacity and wind energy increased by 303 (24%) and 487 GW (11%) [2]. Technological advances in RES and the perceived escalation of energy and environmental crises have led to intense research efforts in hybrid renewable energy systems such as PV-wind [3]; [4].

With low cost, good performance, and indigenous and eco-friendly technology [5], wind energy in production and distribution technology can be connected to a PV system to create a PV-wind hybrid system that offers stability and reliability [6]. Hybrid wind-solar systems have grown dramatically in number over the last few decades, generating electricity around the world [7]. Notable examples of wind-solar power plants are: Iran's first hybrid power plant (Melerd, Mazandaran Province) [8], the USA's first solar-wind hybrid power project (rural Minnesota) [9], the world's largest solar-wind power plant (Anantapur, state of Andhra Pradesh) [10].

HOMER software is used in many cases to optimize RES [11]. In 2016, Bahramara et al. investigated research and advanced studies by HOMER software in the planning of hybrid RES. The noteworthy results of this research are as follows: I) the software was used for a wide range of loads (0.626 to 2213000 kW), II) PV is a popular source for many researchers, III) hybrid RES is modeled in standalone mode more often than connected to the grid, and finally, IV) wind speed, solar radiation, fuel price, cost of components and initial load are often mentioned in the articles as uncertain parameters [12].

In the following, recent works on the modeling of combined RES, PV-wind, by HOMER software, are mentioned.

In southern, Saharan Algeria electricity is supplied by diesel generators, which are inefficient, expensive, loud and environmentally undesirable. The best alternatives come in the form of solar and wind energy, which have high potential.

In 2016, Bentouba and Bourouis investigated the technical and economic hybrid production system for Timiaouine's electricity demand, a settlement with

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more than 200 families located in southwest Algeria. The simulation made with Homer software showed that 100% of the town's electricity demand could be met by using a combined system consisting of a wind power system, a PV system and a diesel generator as a backup system. The cost of electricity generated by the system was estimated at 0.176 $/kWh [13].

In 2017, Boussetta et al. conducted a technical and economic study with HOMER in order to assess the use of a PV-wind hybrid micro-grid system to power the infrastructure of a typical city in Morocco with energy consumption of 4874 kWh/month under different climatic conditions. The results showed that a PV-wind hybrid micro grid system is a desirable solution for use in all regions of the country except the eastern regions, where the average wind speed is low throughout the year [14].

In 2017, Lipu et al. used HOMER software to perform an optimization and sensitivity analysis of a hybrid RES system for St. Martin's Island, Bangladesh. The results showed that a PV-wind-diesel system is the best design for the island in terms of energy cost, followed by PV-diesel, PV-Wind, wind and the PV system at later stages [15].

The present paper uses HOMER software to assess the potential of renewable energy production in Japan. According to studies, this has not previously been done in Japan. Using NASA's 20-year-average weather data, 198 stations in Japan were surveyed and the technical, economic, and environmental parameters of these stations compared, and the best stations are introduced in each scenario.

2. Location of the case

As shown in Fig. 1, Japan is a country in eastern Asia, with a population of 127 million in 2016 [16]. Japan has a highly advanced and diversified economy, but it has few indigenous energy resources and imports 84% of its primary energy needs, mainly in the form of oil and natural gas [17]. Given the shortage of domestic fossil fuels and the increase of pollutants in Japan, in 2009, long-term energy strategy was focused mainly on increased use of nuclear energy [18]. In 2008, nuclear power plants supplied 14% of Japan's total primary energy, but that dropped to 1% in 2013 [1].

The Fukushima Daiichi nuclear disaster in March 2011 revolutionized the approach to energy supply, marking the beginning of a transition to greater use of renewable energy systems [19]. In April 2015, the Japanese government announced that it would increase its share

Figure 1: Japan's place in the world.

of renewable energy in total electricity generation from 13% (including large hydroelectric power) to 22-24% by 2030 [20] and the possibility was raised of meeting 100% of electrical energy demand from renewable energy sources by 2050 [21]. In 2016, as seen in Fig. 2, the share of renewable energy in electricity production in Japan increased to 15% [22].

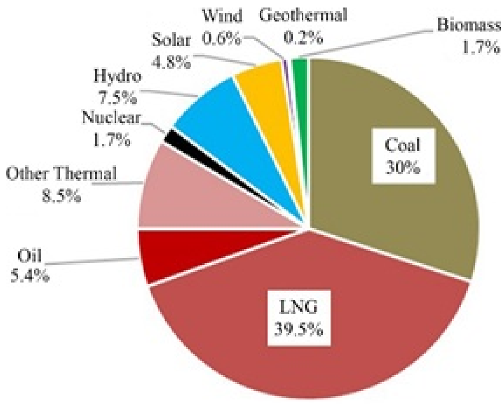

Figure 2: The share of various sources of electricity generation in Japan in 2016

In response to the government's fiscal policies, renewable technologies, especially PV and wind, are experiencing sustained growth [23]. Wind energy has a higher potential than other renewable energies in Japan [24]. Japan Wind Power Association estimates that on- and offshore wind energy generation will be 50 GW or more by 2050 [25]. Evidently, barriers such as grid limited capacity, current market power structure and grid operating methods by existing electricity companies restrict network access to wind projects [24]. The installed cumulative wind capacity at the end of 2016 was 3.2 GW, while it was 42.8 GW for photovoltaic [26].

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Size of equipment	Lifetime	Operating & Maintenance ($)	Replacement ($)	Purchase ($)	Component
0-4	20 year	0	3000	3200	PV
0-20	845 kwh	5	174	174	Battery Trojan T-105
0-2	20 year	100	3650	5725	Wind turbine BWC XL.1
0-2	10 year	10	200	200	Converter
0-2	15000 hour	0.5	200	200	Generator

Table 1: Simulated hybrid power information [27]

3. HOMER software

HOMER software is a computer model designed by the National Renewable Energy Research Laboratory (NREL) to evaluate and design power systems connected to the grid or standalone. HOMER can be used for distributed generation and remote areas. The software calculates the energy balance by specifying whether the designed system is possible or not and then estimates the cost of installing and operating the system throughout the project [28]; [29]. System cost calculations are made for costs such as initial investment, replacement and maintenance, either annually or hourly. As the most important economic output, the software provides a list of categorized systems based on total NPC. Total NPC represents all costs that are imposed on the system throughout the lifetime of the project (installation, replacement, fuel, electricity purchase from the network and penalty of emissions) minus the system's revenues (revenue from sale of electricity to the grid and proceeds from the sale of equipment).

4. Problem descriptions and data required

4.1. Radiation and wind speed information

In the present work, using data extracted from the NASA website and the RETScreen 4 software that are 20-year average figures [30], a technical-economic-environmental study of wind-solar power plants was performed in relation to 198 stations in Japan. The data used in the study are given in the Appendix: solar radiation, wind speed, clearness index, geographic location and altitude.

From the results of Table 1 of the Appendix, it is clear that Iwojima and Urakawa stations have the highest and lowest radiation levels, with annual average values of 5.435 kWh/m²-day and 2.723 KWh/m²-day, respectively. Fuji Mountain and Chichibu stations have the highest and lowest wind speed, with annual average values of 12 m/s and 1.6 m/s, respectively.

The highest station is Fuji Mountain, 3773 m above sea level, and the lowest altitude is Namiestation, at sea level. According to the following formula, in calculating the wind turbine power output, the height above sea level is important, because air density affects turbine performance [31].

$$P_{WTG} = \frac{\rho}{\rho_0} \times P_{WTG,STP} \qquad (1)$$

Where ρ is the actual air density, ρ_0 is air density in standard conditions and P_{WTG} is wind turbine output power. The power curve of the wind turbine is shown in Fig. 3. As can be seen, the cut-in and cut-out speeds of the wind turbine are 2.5 m/s and 13 m/s, respectively.

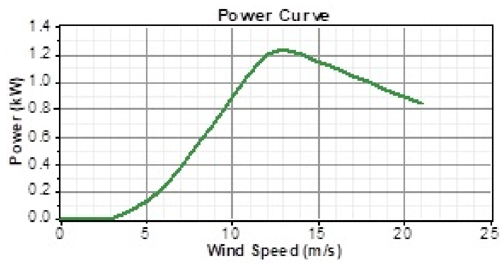

Figure 3: The power curve of BWC XL.1 wind turbine.

The geographic location of the investigated place is important to calculate the clearness index by HOMER software, which requires an amount of radiation above the atmosphere. This can be calculated using the latitude and longitude of the location of interest [32]. The following equation is used to calculate the clearness index [31]:

$$\overline{k}_T = \frac{\overline{H}}{\overline{H}_{oh}} \qquad (2)$$

where

$\overline{H}$

is monthly average daily irradiation on a horizontal plane at the Earth's surface and

$\overline{H}_{oh}$

is monthly average daily value of extraterrestrial radiation energy falling on a horizontal plane. The two-parameter Weibull function is often used to determine the wind regime because it is a good fit with measured wind data [31]. The probability density function or the Weibull function is obtained by the following equation:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}\exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad (3)$$

where v is wind speed in m/s, k is a shape factor that is dimensionless and c is the Weibull scale parameter in m/s. To determine k and c using the analytical and empirical methods, the Justus formula is used [33]:

$$k = \left(\frac{\sigma_U}{\overline{U}}\right)^{-1.086} \qquad (4)$$

$$\frac{c}{\overline{U}} = \frac{k^{2.6674}}{0.184+0.816k^{2.73855}} \qquad (5)$$

where σ_U is standard deviation and

$$\overline{U}$$

is average speed. The standard deviation obtained from the following equation:

$$\sigma_U = \overline{U}\sqrt{\frac{\Gamma(1+\frac{2}{k})}{\Gamma^2(1+\frac{2}{k})} - 1} \qquad (6)$$

In Equation (5), the coefficient c points to the windiness of the region and the k Weibull or Weibull shape factor is a parameter that indicates the extent of wind distribution. The HOMER software fits the Weibull distribution on wind speed data, and k refers to its shape. The lower values of k values are related to the wider distribution of wind speed. This means that wind speed varies widely. Large k values correspond to small wind speed distribution. In HOMER, the default is k=2, which usually occurs in strong wind regimes. To fit the Weibull distribution on wind speed data, HOMER uses the maximum likelihood method. The values of k and c for 198 stations are shown in Table 2 of the Appendix. The results show that the widest range of wind speed is at Iwakuni, Kansai International, Ofunato, Onahama, Shimofusa and Toyooka stations with k = 2.04 and Fuji Mountain is the windiest area with c = 13.56.

4.2. Diesel consumption data and equipment prices

The price of diesel, 0.99 $ per liter, is imported into the software [34]. The real annual interest rate in Japan is -0.1% [35]. The lifetime of the project is 25 years. As the main economic output, the software presents a list of categorized systems based on total NPC. Total NPC represents all costs that are imposed on the system throughout the life of the project (installation, replacement, fuel, electricity purchase from the grid and fines for emissions) minus system revenues (Revenues from sale to the grid and the sale of used equipment). Total NPC is calculated [36]:

$$NPC = \frac{C_{ann,total}}{CRF(i,R_{proj})} \qquad (7)$$

In the above relationship, $C_{ann,total}$ is total annual cost, CRF is cost recovery factor, i real interest rate and R_{proj} is the lifetime of the project. All costs and revenues are evaluated at a fixed interest rate throughout the year. In this assessment, for the purpose of reflecting inflation in calculations, the actual interest rate resulting from inflation is calculated and the effect of the change in the interest rate on final NPC is applied. The cost recovery factor, which indicates cost recovery over N years, is calculated [36]:

$$CRF = \frac{i(1+i)^N}{(1+i)^N-1} \qquad (8)$$

The software calculates the annual interest rate through the following equation [36].

$$i = \frac{i'-f}{1+f} \qquad (9)$$

The cost per kWh of energy during the lifetime of the project is obtained by software from the following equation [36]:

$$COE = \frac{C_{ann,total}}{E_{LoadServed}} \qquad (10)$$

In the above equation, $E_{Load\ Served}$ is the real electric load in a hybrid system with unit kWh/yr.

In Table 1, the prices, size, lifetime, and other useful information related to the used components in the simulation are given. It should be noted that the angle of the solar cells is aligned to the latitude of the investigated area, and the solar cells lack a solar tracking system. The capacity of a battery is defined as the amount of energy that can be withdrawn from it starting from a fully-charged state and depends on the rate at which energy is withdrawn from it. Higher discharge current is related to lower capacity. In a lifetime test, the tester subjects the battery to repeated regular charge and discharge cycles. The lifetime test determines how many such cycles the battery can withstand before it needs replacement. In HOMER software battery lifetime is calculated from the following equation [31]:

$$Q_{lifetime} = f_i d_i \frac{q_{max} V_{nom}}{1000W/kW} \qquad (11)$$

where $Q_{lifetime,i}$ is the lifetime throughput (kWh), f_i is the number of cycles to failure, d_i is the depth of discharge (%), q_{max} is the maximum capacity of the battery (Ah) and V_{nom} is the nominal voltage of the battery (V). The model of the battery used in the simulation is Trojan T-105 with a nominal capacity of 225 Ah and a nominal voltage of 6 V. The capacity curve and lifetime curve are presented in Figs. 4 and 5 in the form of discharge current (A) versus capacity

(Ah) and cycles to failure versus depth of discharge (%), respectively.

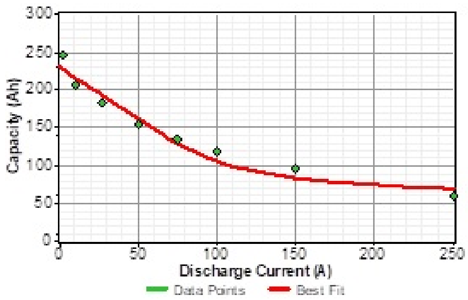

Figure 4: The capacity curve of Trojan T-105 Battery.

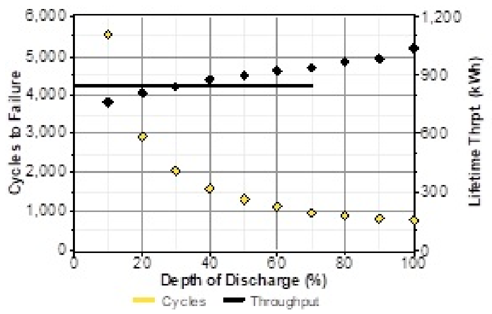

Figure 5: The lifetime curve of Trojan T-105 Battery.

4.3. Power consumption information

The average amount of daily consumed energy in kW of a home is obtained over a year, as shown in Fig. 6. In July demand peaks for electricity at 806 W, while the highest average monthly electricity demand is 308 W in August. Average annual electricity consumption is 246.7 W and the load factor, dividing the average annual consumption of electricity into the demand peak, is 0.306.

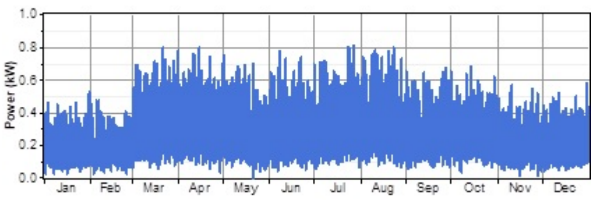

Figure 6: Average amount of daily consumed electricity.

5. Results

The schematic of the designed hybrid wind-solar system in the software is shown in Fig. 7. When generated electricity exceeds demand, excess electricity is stored in the battery for use at peak time. When there is no wind or solar energy or their intensity is low and use lacks economic justification or the batteries are empty, the diesel generator is used as a backup system. *****IN THE IMAGE BELOW IT SHOULD READ "ELECTRICAL LOAD"*******

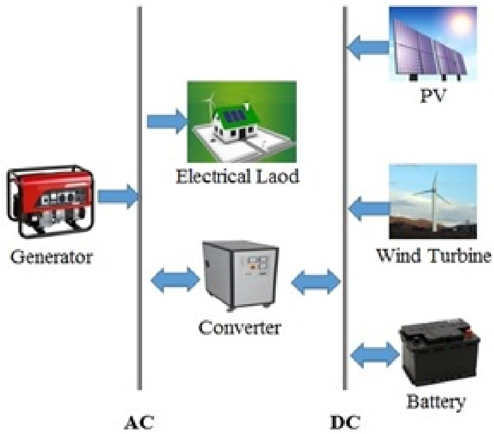

Figure 7: The schematic of the designed hybrid system in the software

The results of the survey on the use of a renewable-energy hybrid system at 198 stations in Japan are presented in Table 3 of the Appendix. The results indicate that the average total NPC is $23761.58, the average percentage of renewable energy usage is 96.2% and the average price per kilowatt-hour of generated power is $ 0.434. By comparison, the electricity cost of the national grid in Japan is 0.23 $/kWh in 2017 [37]. At Fuji Mountain & Murutomisaki stations, the hybrid wind/diesel generator/battery system is cost-effective. At other stations, the use of a hybrid solar/diesel generator/battery and solar/wind/diesel generator/battery systems is cost-effective. The main reasons for this efficiency are as follows: I) solar potential is more suitable than wind energy [32], II) the costs of purchase and maintenance of solar cells are lower than wind turbines.

The cheapest wind hybrid system in Japan, with total NPC of $ 16099, is also the most cost-effective hybrid system in all of Japan. This system costs $ 0.294/kWh of electrical power and is related to Mount Fuji Station. The system includes 1 wind turbine, 1 diesel generator, 9 batteries, and 1 converter. The wind energy percentage of the system is 98%.

The cheapest solar/wind hybrid system with total NPC of $18532 is located at Iwojima station. The price of electricity generated by the station is $ 0.339/kWh. This system includes 1 solar cell, 1 wind turbine, 8 batteries, and 1 converter. The percentage of renewable energy usage is 100%. The most expensive hybrid system, with total NPC of $ 28785 and 89% renewable energy, is located at Tokyo station. The price of electricity generated by this station is $ 0.526/kWh. This station includes 3 solar cells, 1 diesel generator, 19 batteries, and 1 converter. Due to the diesel generator used as backup in the investigated hybrid system, CO_2 is produced. Japan is the fifth largest generator of CO_2 in the world [38]. Therefore, the issue of the amount of CO_2 generated is considered. The lowest carbon dioxide figure, zero kg/year, is for Iwojima station and the highest amount of CO_2, 1143 kg/year, is produced at Omu station.

Iwojima station is very suitable for solar energy. As shown in Table 1 of the Appendix, it has the highest average annual radiation in Japan, with a rate of 5.435 kWh/m^2-day. Unlike other stations, Iwojima does not have a diesel generator system.

In Table 5 of the Appendix, the details of electricity produced over a year at Fuji Mountain, Minamitorishima, Iwojima and Tokyo stations are shown. Those stations have: the cheapest wind hybrid system, cheapest solar hybrid system, cheapest wind-solar hybrid system, and the most expensive hybrid system in Japan, respectively.

Considering the results of Table 5 of the Appendix for Fuji Mountain, the wind is sufficient for 10 months of the year and no fossil fuels (generator) are required. The highest generator use occurs in August. 1573 kWh/year excess electricity is generated, which is about 38.5% of the total produced electricity. The excess electricity can be sold to the national electricity grid and reduces the return time for investors. In addition, the wind turbine has an operating time of 7179 hours per year, which shows that for 82% of the year the wind speed exceeds 3 m/s, the speed required to operate a wind turbine. For 55 hours, about 0.6% of the year, energy is generated by diesel generators. This is used when there is no wind and the batteries are empty or cannot be responsive to consumers. For the rest of the year, energy is provided by the energy stored in the batteries.

In addition to balancing energy between supply and demand, it is also very important to use electrical energy storage for the purpose of adjusting the frequency of oscillations and the voltage of the grid. Batteries have 3 potential dropouts, each of which is important in the special current range I) energy losses due to mass transfer limitation for reactors and products (high current), II) energy losses due to the resistance of the electrodes, connections, etc. (intermediate current) and III) energy losses due to electrode reaction (low current). Also, there are three types of losses in converters: Ohm losses, magnetic field losses, and switching losses [39]. Due to these losses, there is a slight drop in the converter and the rectifier. Therefore, the efficiency of the batteries and converters is not 100% and there are 115 kWh, 239 kWh and 4 kWh of losses per year in batteries, converters, and rectifiers, respectively, at Fuji Mountain Station.

As shown in Tables 3 and 5 of the Appendix, Iwojima Station is the only station in Japan with 100% renewable energy. It is clear the wind power at this station performs better than solar power in terms of producing electricity. Throughout the year, the amount of energy produced by the wind turbine is greater than that of the solar cell. The excess produced electricity is 2743 kWh/yr, which is about 52% of the total 5258 kWh of produced energy per year. It is produced by 1890 hours of solar cells. Battery losses are 114 kWh during the year. Another result that can be seen from Table 5 of the Appendix is that the loss of AC to DC is zero in the rectifier. This is due to no use of the generator in generating AC.

The results of Table 5 of the Appendix for Minamitorishima show solar radiation is sufficient for 10 months of the year, with no need to use fossil fuels during that time (generator). The generator is mainly used in March. Also, the surplus generated electricity is 1015 kWh/year, which is about 27.8% of the total electricity produced. The surplus electricity can be sold to the national electricity grid and reduces the return time for investors. The operating hours of the solar cell are 4379 hours in a year, indicating that the solar cell meets electricity demand for 50% of the year and the diesel generator is used for 29 hours, about 0.33% of the year. This is used when there is no radiation and batteries are empty or cannot be responsive to consumers. The rest of the year, energy is provided by the stored energy in the batteries.

As shown in Table 5 of the Appendix for Tokyo, it is observed that solar radiation is insufficient in all the months except January and February. Therefore, the use of a diesel generator is inevitable. The most solar energy produced is 0.41 kW in August and the most diesel generator use is 0.06 kW in September. The lowest solar energy produced is 0.29 kW in October. In total, at Tokyo Station 815 kWh of excess electricity is produced during the year, which accounts for 23.5% of the total electricity produced. It is produced during 4358 hours of solar cell operation and 265 hours of diesel generator operation. The battery, inverter and rectifier losses in kWh are 228, 233, and 25, respectively.

6. Conclusion

The Japanese government provides support to the R&D unit in the field of energy, where the main topics of research are the optimization of energy consumption and the use of renewable energy. As related above, 198 stations in Japan were studied using NASA's solar radiation data and wind speed data. HOMER software was used for analysis purposes and the main results are as follows:

- The average, maximum, and minimum usage of renewable energy in Japan are 96.2%, 100%, and 89%, respectively.

- The average, maximum, and minimum cost per kWh of energy are $ 0.434, $ 0.526, and $ 0.294, respectively.

- In the cheapest wind system (the cheapest renewable energy system), the cheapest solar system, the cheapest wind-solar system and the most expensive hybrid system, the total NPC is $ 16099, $ 19075, $ 18532 and $ 28785, respectively, and related to Fuji Mountain, Minamitorishima, Iwojima and Tokyo stations.

- The lowest amount of CO_2 is produced by Iwojima station, zero kg/year, and the largest amount of CO_2 is produced by the Omu station, 1143 kg/year.

- At Fuji Mountain and Murutomisaki stations, only wind power is used to supply electricity.

Station	Longtitude	Latitude	Elevation (m)	Wind (m/s)	Solar (kwh/m2-day)	Clearness index
Abashiri	144.3	44	43	3.4	3.7	0.497
Aburatsu	131.4	31.6	15	4.8	3.7	0.457
Aikawa	138.2	38	17	4.8	3.9	0.487
Ajiro	139.1	35.1	68	3	3.7	0.457
Akita	140.1	39.7	21	4	3.2	0.411
Akune	130.2	32	45	3.3	3.9	0.455
Aomori	140.8	40.8	3	3.7	3.7	0.479
Asahikawa	142.4	43.8	116	2.1	3.3	0.445
Ashiya (JASDF)	130.7	33.9	33	3.9	3.9	0.463
Asosan	131.3	32.9	1144	4.7	3.7	0.44
Atsugi (Nas)	139.5	35.5	65	3.9	3.8	0.457
Chiba	140.1	35.6	19	4.2	3.7	0.452
Chichi Jima Bonin Is	142.2	27.1	8	3.4	4.4	0.497
Chichibu	139.1	36	234	1.6	3.8	0.462
Chitose (Jasdf)	141.7	42.8	27	4.1	3.3	0.436
Chitose (JASDF/Civ)	141.7	42.8	30	4.1	3.3	0.436
Choshi	140.9	35.7	28	5.6	3.7	0.455
Esashi	140.1	41.9	12	4.7	3.3	0.439
Fuji Mountain (Aut)	138.7	35.4	3773	12	3.9	0.476
Fukaura	139.9	40.7	67	3	3.8	0.488
Fukue	128.8	32.7	26	3.4	4	0.478
Fukui	136.2	36.1	17	2.9	3.8	0.465

Table 2 continued from previous page

Station	Longtitude	Latitude	Elevation (m)	Wind (m/s)	Solar (kwh/m2-day)	Clearness index
Fukuoka	130.4	33.6	15	2.9	3.5	0.421
Fukuoka/Itazuke	130.5	33.6	12	3.5	3.9	0.463
Fukushima	140.5	37.8	69	2.5	3.5	0.432
Fukuyama	133.3	34.5	3	1.8	3.6	0.438
Fushiki	137.1	36.8	13	2.8	3.4	0.421
Futenma	127.8	26.3	84	4.4	4.4	0.49
Gifu	136.8	35.4	17	2.7	3.5	0.426
Gifu (JASDF)	136.9	35.4	42	2.3	3.5	0.426
Haboro	141.7	44.4	10	4.03	3.5	0.473
Hachijojima/Omure	139.8	33.1	80	5.5	4.2	0.495
Hachinohe	141.5	40.5	28	3.9	3.3	0.428
Hagi	131.4	34.4	7	3.2	3.9	0.472
Hakodate	140.8	41.8	43	3.5	3.3	0.439
Hamada	132.1	34.9	20	3.8	3.6	0.43
Hamamatsu	137.7	34.7	33	3.5	3.9	0.472
Hamamatsu (JASDF)	137.7	34.8	48	3.7	3.9	0.472
Hikone	136.3	35.3	89	2.9	3.5	0.426
Himeji	134.7	34.8	40	3	3.7	0.448
Hirado Island	129.6	33.4	59	3.6	4.2	0.496
Hiroo	143.3	42.3	33	2.9	3.4	0.458
Hiroshima	132.5	34.4	53	3.8	3.6	0.429
Hita	130.9	33.33	84	1.6	3.9	0.462
Hitoyoshi	130.8	32.2	147	1.7	3.9	0.455
Hofu (JASDF)	131.6	34	5	3.4	3.9	0.472
Hyakuri (JASDF)	140.4	36.2	35	3.1	3.7	0.451
Iizuka	130.7	33.7	38	2.4	3.9	0.463
Irako	137.1	34.6	8	4.1	3.9	0.472
Lida	137.8	35.5	529	2.03	3.9	0.471
Irozaki (Cape)	138.9	34.6	56	4.6	4.08	0.486
Iruma (JASDF)	139.4	35.8	93	2.9	3.8	0.458
Ishigakijima Island	124.2	24.3	6	4.9	4.2	0.459
Ishinomaki (Point)	141.3	38.4	43	4.2	3.5	0.439
Itoigawa	137.9	37	11	5.5	3.9	0.486
Iwakuni	132.2	34.2	3	2.5	3.6	0.429
Iwamizawa	141.8	43.2	51	3.5	3.4	0.458
Iwojima (JMSDF)	141.3	24.8	116	5.7	5.4	0.592
Izuhara	129.3	34.2	19	3.1	4.3	0.519
Izumo	132.8	35.4	66	5.5	4.09	0.492
Kadena (USAF/Navy)	127.8	26.4	45	4.5	4.4	0.49
Kagoshima/Yoshino	130.6	31.6	32	2.6	3.8	0.444
Kanazawa	136.6	36.6	33	3.8	3.8	0.465
Kanoya (JMSDF)	130.8	31.4	68	4.1	4.01	0.464
Kansai Internationa	135.3	34.4	8	4.6	3.8	0.461
Karuizawa	138.6	36.4	1004	1.9	3.6	0.442
Katsuura	140.3	35.2	13	3.3	3.7	0.455
Kawaguchiko	138.8	35.5	861	1.9	3.9	0.476
Kitami	143.9	43.8	467	5.3	3.3	0.448
Kitamiesashi	142.6	44.9	8	3.1	3.3	0.446
Kobe	135.2	34.7	30	3.4	3.1	0.376
Kochi	133.6	33.6	5	2.06	3.7	0.442
Kofu	138.6	35.7	281	2.2	3.9	0.475
Komatsu (Civ/JASDF)	136.4	36.4	9	3.4	3.8	0.465

Table 2 continued from previous page

Station	Longtitude	Latitude	Elevation (m)	Wind (m/s)	Solar (kwh/m2-day)	Clearness index
Komatsujima (JASDF)	134.6	34	6	5.5	3.7	0.447
Kumamoto	130.7	32.8	39	2.3	3.7	0.432
Kumejima	126.8	26.3	5	3.8	4.2	0.437
Kure	132.6	34.2	5	2.3	3.6	0.429
Kumgaya	139.4	36.2	31	2.6	3.6	0.442
Kushiro/Kenebetsu	144.4	43	39	4.1	3.7	0.492
Kutchan	140.8	42.9	188	3.1	3.2	0.425
Kyoto	135.7	35	46	1.9	3.6	0.437
Maebashi	139.1	36.4	113	3.08	3.6	0.443
Maizuru	135.3	35.5	22	2.4	3.6	0.438
Makurazaki	130.3	31.3	31	4.2	4.01	0.464
Matsue	131.1	35.5	22	3.4	3.8	0.46
Matsumoto	138	36.3	611	2.5	4	0.487
Matsushima (JASDF)	141.2	38.4	5	3.9	3.5	0.439
Matsuyama	132.8	33.9	34	2.1	4.3	0.512
Miho (Civ/JASDF)	133.2	35.5	9	4.07	3.8	0.46
MinamidaitojimaIsl	131.2	25.8	20	4.6	4.9	0.539
Minamitorishima	154	24.3	8	5.3	5.2	0.57
Misawa (Npmod)	141.4	40.7	39	4.5	3.3	0.429
Mishima Island	138.9	35.1	22	2.2	3.9	0.476
Mito	140.5	36.4	31	2.4	3.2	0.398
Miyakejima Island	139.5	34.1	22	2.2	4	0.487
Miyako	142	39.7	46	2.5	3.6	0.446
Miyakojima Island	125.3	24.8	41	4.9	3.6	0.502
Miyakonojo	131.1	31.7	156	2.1	3.6	0.457
Miyazaki	131.4	31.9	15	3.1	3.6	0.457
Mombetsu	143.4	44.4	16	3.4	3.6	0.487
Morioka	141.2	39.7	155	3.09	3.3	0.421
Muroran/Yakumo	141	42.3	49	4.7	3.2	0.424
Muruotomisaki (Cape)	134.2	33.3	186	7.7	3.9	0.462
Mutsu	141.2	41.3	5	2.9	3.6	0.466
Nagano	138.2	36.7	419	2.6	3.9	0.483
Nagasaki	129.9	32.7	35	2.4	4.1	0.486
Nagoya	137	35.2	56	3.1	3.5	0.426
Nagoya (Civ/JASDF)	136.9	35.3	17	3.1	3.5	0.426
Naha (Civ/JASDF)	127.7	26.2	6	5.1	4.4	0.49
Naha Airport	127.7	26.2	53	5.3	3.9	0.435
Nakamura	132.9	33	14	5.4	4.1	0.492
Nakashibetsu	145	43.6	190	5.4	3.5	0.468
Namie	141	37.5	0	5.4	3.7	0.463
Nara	135.8	34.7	106	1.6	3.8	0.461
Naze/Funchatoge	129.5	28.4	73.1	2.6	4.18	0.47
Nemuro	145.6	43.3	39	5.1	3.5	0.472
New Tokyo Intl Arpt	140.4	35.8	44	3.6	3.7	0.455
Niigata	139.1	37.9	6	3.7	3.3	0.417
Nikko	139.5	36.7	1294	3.2	3.6	0.443
Nobeoka	131.7	32.6	21	2.2	3.7	0.44
Nyutabaru (JASDF)	131.5	32.1	82	3.3	3.7	0.44
Obihiro	143.2	42.9	43	2.3	3.4	0.458
Ofunato	141.7	39.1	41	2.6	3.3	0.42
Oga	139.8	39.9	10	5.1	3.8	0.487
Oita	131.6	33.2	13	2.7	3.7	0.442

Table 2 continued from previous page

Station	Longtitude	Latitude	Elevation (m)	Wind (m/s)	Solar (kwh/m2-day)	Clearness index
Okayama	133.9	34.7	18	3.04	3.6	0.438
Okinoerabu/Okierabu	128.7	27.4	29	5.5	4.3	0.484
Omaezaki (Cape)	138.2	34.6	47	5.04	4.08	0.486
Ominato (JASDF)	141.1	41.2	10	4.5	3.6	0.477
Omu	143	44.6	15	3.2	3.3	0.446
Onahama	140.9	37	5	2.9	3.7	0.456
Osaka	135.5	34.7	83	3.2	3.09	0.367
Osaka Intl/Itami	135.4	34.8	15	3.1	3.8	0.461
Oshima Island	139.4	34.8	79	5.3	4.1	0.488
Otaru	141	43.2	26	2.8	3.4	0.458
Owase	136.2	34.1	27	2.3	3.6	0.439
Ozuki (JMSDF)	131.1	34.1	7	3.5	3.9	0.472
Rumoi	141.6	44	28	5.05	3.4	0.464
Saga	130.3	33.3	32	3.1	3.9	0.462
Saigo	133.3	36.2	31	3.5	4.6	0.561
Sakai	133.2	35.6	3	2.3	3.8	0.46
Sakata	139.9	38.9	4	4.4	3.7	0.462
Sapporo	141.3	43.1	26	3.05	3.3	0.446
Sasebo	129.7	33.2	6	2.8	4.2	0.496
Sendai	140.9	38.3	43	3.4	3.4	0.432
Shimizu/Ashizuri	133	32.7	33	3.5	4.06	0.473
Shimofusa (JMSDF)	140	35.8	33	3.2	3.7	0.455
Shimonoseki	130.9	34	19	3.4	3.9	0.467
Shingu	136.9	33.7	8	5.2	4.1	0.488
Shinjo	140.3	38.8	102	2.9	3.3	0.413
Shionomiski (Cape)	135.8	33.5	75	4.3	4.02	0.474
Shirakawa	140.2	37.1	357	3.5	3.5	0.431
Shizuhama (JASDF)	138.3	34.8	10	3.8	4.08	0.486
Shizuoka	138.4	35	15	2.3	4.08	0.491
Sukumo	132.7	32.9	11	2.9	4.18	0.487
Sumoto	134.9	34.3	112	2.7	3.7	0.447
Suttsu	140.2	42.8	38	3.7	3.2	0.425
Suwa	138.1	36.1	762	3.07	3.6	0.442
Tadotsu	133.8	34.3	5	2.6	3.6	0.438
Takada	138.3	37.1	18	2.3	3.7	0.461
Takajama	137.3	36.2	561	1.7	3.4	0.42
Takamatsu	134.1	34.3	10	2.6	3.7	0.448
Tanegashima Island	131	30.7	18	4.7	4.1	0.475
Tateno	140.1	36.1	25	4.2	3.6	0.443
Tateyama	139.9	35	7	3.02	4.1	0.493
Tateyama (JMSDF)	139.8	35	6	4.4	4.1	0.493
Tokushima	134.6	34.1	6	3.2	3.7	0.447
Tokushima (JMSDF/Cv)	134.6	34.1	11	4.6	3.7	0.447
Tokyo	139.8	35.7	36	3.3	2.9	0.359
Tokyo Intl Airport	139.8	35.6	9	5.07	3.8	0.457
Tomakomai	141.6	42.6	11	3.1	3.3	0.436
Tottori	134.2	35.5	15	3.2	3.2	0.395
Toyama	137.2	36.7	17	3.03	3.4	0.421
Toyooka	134.8	35.5	4	1.7	3.7	0.454
Tsu	136.5	34.7	18	4.2	3.6	0.439
Tsuiki (JASDF)	131.1	33.7	20	3.4	3.7	0.445
Tsuruga	136.1	35.7	12	4.2	3.5	0.427

Table 2 continued from previous page

Station	Longtitude	Latitude	Elevation (m)	Wind (m/s)	Solar (kwh/m2-day)	Clearness index
Tsuyama	134	35.1	147	1.7	3.6	0.444
Ueno	136.2	34.8	161	2.6	3.6	0.439
Unzendake (Mount)	130.3	32.7	679	2.5	3.9	0.455
Urakawa	142.8	42.2	37	4.4	2.7	0.357
Ushibuka	130.3	31.7	14	2.8	4.01	0.464
Utsunomiya	139.9	36.6	140	3	3.7	0.452
Uwajima	132.6	33.2	14	3.02	4.3	0.512
Wajima	136.9	37.4	14	3.7	3.3	0.409
Wakamatsu	139.9	37.5	213	2.1	3.3	0.417
Wakayama	135.2	34.2	18	3.8	3.8	0.46
Wakkanai	141.7	45.4	11	4.6	3.4	0.477
Yakushima Island	130.7	30.4	38	4.3	4.1	0.475
Yamagata	140.4	38.3	153	1.8	3.3	0.413
Yamaguchi	131.5	34.2	18	1.9	3.9	0.472
Yokkaichi	136.6	34.9	56	2.5	3.6	0.439
Yokohama	139.7	35.4	42	3.6	3.8	0.457
Yokosuka	139.7	35.3	53	4.4	3.8	0.457
Yokota (JASDF/USAF)	139.4	35.8	139	2.7	3.8	0.457
Yonago	133.3	35.4	8	2.9	3.5	0.432
Yonagunijima	123	24.5	36	6.7	4.2	0.459

Table 2: Appendix Table 1

Station	K	c	Station	K	c
Abashiri	2	3.87	Morioka	1.96	3.49
Aburatsu	1.99	5.49	Muroran/Yakumo	1.97	5.32
Aikawa	1.95	5.43	Muruotomisaki (Cape)	1.98	8.79
Ajiro	1.99	3.43	Mutsu	1.96	3.34
Akita	2	4.54	Nagano	2.01	3.03
Akune	1.99	3.79	1.99N3.agasaki	1.97	2.79
Aomori	2.03	4.2	Nagoya	1.97	3.54
Asahikawa	1.96	2.44	Nagoya (Civ/JASDF)	1.96	3.58
Ashiya (JASDF)	2.03	4.43	Naha (Civ/JASDF)	1.98	5.86
Asosan	1.98	5.35	Naha Airport	2	6
Atsugi (Nas)	1.97	4.41	Nakamura	2.01	6.13
Chiba	1.96	4.74	Nakashibetsu	1.95	6.09
Chichi Jima Bonin Is	1.97	3.85	Namie	1.99	6.12
Chichibu	2.03	1.85	Nara	2.03	1.86
Chitose (Jasdf)	2	4.65	Naze/Funchatoge	1.95	3
Chitose (JASDF/Civ)	2	4.7	Nemuro	2.02	5.82
Choshi	1.98	6.35	New Tokyo Intl Arpt	1.97	4.06
Esashi	1.98	5.34	Niigata	2	4.22
Fuji Mountain (Aut)	1.99	13.56	Nikko	1.99	3.64
Fukaura	1.99	3.39	Nobeoka	2.02	2.59
Fukue	1.97	3.89	Nyutabaru (JASDF)	1.99	3.79
Fukui	1.98	3.34	Obihiro	2	2.61
Fukuoka	1.99	3.37	Ofunato	2.04	3.01
Fukuoka/Itazuke	1.98	4.03	Oga	1.99	5.77
Fukushima	2.03	2.86	Oita	1.97	3.12
Fukuyama	1.98	2.06	Okayama	1.97	3.43

Table 3 continued from previous page

Station	K	c	Station	K	c
Fushiki	1.99	3.17	Okinoerabu/Okierabu	1.971	6.3
Futenma	2	5.01	Omaezaki (Cape)	1.96	5.69
Gifu	1.96	3.09	Ominato (JASDF)	1.96	5.15
Gifu (JASDF)	2.03	2.6	Omu	1.99	3.69
Haboro	1.99	4.55	Onahama	2.04	3.31
Hachijojima/Omure	2.03	6.28	Osaka	1.98	3.69
Hachinohe	1.97	4.45	Osaka Intl/Itami	1.98	3.57
Hagi	2	3.68	Oshima Island	1.99	6.04
Hakodate	1.97	4.04	Otaru	2	3.22
Hamada	1.98	4.38	Owase	1.97	2.69
Hamamatsu	1.99	4.01	Ozuki (JMSDF)	1.99	3.99
Hamamatsu (JASDF)	1.99	4.18	Rumoi	1.99	5.7
Hikone	2.01	3.32	Saga	1.98	3.52
Himeji	1.99	3.42	Saigo	1.99	3.96
Hirado Island	1.97	4.07	Sakai	1.97	2.64
Hiroo	1.99	3.27	sakata	2	5.03
Hiroshima	1.97	4.31	Sapporo	1.97	3.44
Hita	1.96	1.91	Sasebo	1.99	3.19
Hitoyoshi	1.96	1.95	Sendai	2.03	3.9
Hofu (JASDF)	1.98	3.89	Shimizu/Ashizuri	1.99	4.02
Hyakuri (JASDF)	2.01	3.52	Shimofusa (JMSDF)	2.04	3.62
Lida	2.01	2.29	Shimonoseki	2.03	3.94
Iizuka	1.96	2.72	Shingu	1.97	5.94
Irako	2.02	4.72	Shinjo	2.03	3.27
Irozaki (Cape)	1.97	5.2	Shionomiski (Cape)	2	4.95
Iruma (JASDF)	2.02	3.33	Shirakawa	1.98	4.02
Ishigakijima Island	1.99	5.55	Shizuhama (JASDF)	2	4.3
Ishinomaki (Point)	2.03	4.84	Shizuoka	1.98	2.66
Itoigawa	1.95	6.3	Sukumo	1.99	3.27
Iwakuni	2.04	2.91	Sumoto	1.95	3.15
Iwamizawa	1.99	3.98	Suttsu	1.95	4.25
Iwojima (JMSDF)	1.97	6.5	Suwa	1.95	3.46
Izuhara	1.98	3.58	Tadotsu	2.03	2.98
Izumo	1.97	6.29	Takada	2.02	2.69
Kadena (USAF/Navy)	2	5.08	Takajama	2.03	2
Kagoshima/Yoshino	1.98	2.98	Takamatsu	1.96	3.01
Kanazawa	2.01	4.3	Tanegashima Island	1.99	5.41
Kanoya (JMSDF)	1.95	4.69	Tateno	1.96	4.84
Kansai Internationa	2.04	5.23	Tateyama	1.97	3.41
Karuizawa	1.99	2.2	Tateyama (JMSDF)	1.96	5.03
Katsuura	1.97	3.75	Tokushima	1.98	3.67
Kawaguchiko	1.96	2.22	Tokushima (JMSDF/Cv)	1.98	5.22
Kitami	1.95	6	Tokyo	1.98	3.79
Kitamiesashi	1.95	3.51	Tokyo Intl Airport	1.98	5.72
Kobe	1.99	3.85	Tomakomai	1.98	3.58
Kochi	1.99	3.34	Tottori	1.97	3.63
Kofu	2	2.56	Toyama	1.98	3.42
Komatsu (Civ/JASDF)	2	3.93	Toyooka	2.04	1.95
Komatsujima (JASDF)	2.03	6.26	Tsu	1.97	4.82
Kumamoto	1.98	2.64	Tsuiki (JASDF)	1.98	3.87
Kumejima	1.99	4.33	Tsuruga	1.96	4.75
Kumgaya	1.99	2.96	Tsuyama	1.98	1.96
Kure	1.96	2.64	Ueno	1.95	3.02

Table 3 continued from previous page

Station	K	c	Station	K	c
Kushiro/Kenebetsu	2.03	4.73	Unzendake (Mount)	1.98	2.87
Kutchan	1.97	3.53	Urakawa	2	5.07
Kyoto	1.95	2.17	Ushibuka	1.99	3.18
Maebashi	1.96	3.48	Utsunomiya	1.99	3.38
Maizuru	1.98	2.74	Uwajima	1.98	3.41
Makurazaki	1.97	4.83	Wajima	1.96	4.28
Matsue	1.96	3.92	Wakamatsu	2.01	2.38
Matsumoto	1.96	2.84	Wakayama	1.98	4.33
Matsushima (JASDF)	2	4.46	Wakkanai	1.96	5.22
Matsuyama	1.99	2.45	Yakushima Island	2	4.94
Miho (Civ/JASDF)	1.98	4.59	Yamagata	1.97	2.13
MinamidaitojimaIsl	1.99	5.19	Yamaguchi	1.96	2.18
Minamitorishima	1.95	6.02	Yokkaichi	1.96	2.89
Misawa (Npmod)	2.03	5.08	Yokohama	1.98	4.11
Mishima Island	1.96	2.56	Yokosuka	1.98	4.96
Mito	1.97	2.73	Yokota (JASDF/USAF)	2.03	3.05
Miyakejima Island	1.96	2.56	Yonago	1.98	3.32
Miyako	1.96	2.82	Yonagunijima	1.99	7.59
Miyakojima Island	1.98	5.57	Tsu	1.97	4.82
Miyakonojo	1.95	2.44	Tsuiki (JASDF)	1.98	3.87
Miyazaki	1.98	3.54	Tsuruga	1.96	4.75
Mombetsu	1.98	3.93			

Table 3: Appendix Table 2

Station	PV	Wind	Generator	Battery	Converter	Total NPC ($)
Abashiri	2	0	1	19	1	23012
Aburatsu	1	1	1	11	1	23181
Aikawa	3	0	1	17	1	24272
Ajiro	3	0	1	18	1	24535
Akita	3	0	1	18	1	26880
Akune	3	0	1	16	1	23505
Aomori	2	0	1	20	1	23934
Asahikawa	3	0	1	18	1	26254
Ashiya (JASDF)	3	0	1	17	1	23371
Asosan	3	0	1	17	1	23777
Atsugi (Nas)	3	0	1	17	1	24304
Chiba	3	0	1	18	1	24109
Chichi Jima Bonin Is	2	0	1	18	1	20936
Chichibu	3	0	1	17	1	24295
Chitose (Jasdf)	3	0	1	19	1	25491
Chitose (JASDF/Civ)	3	0	1	19	1	25491
Choshi	1	1	1	9	1	20905
Esashi	3	0	1	18	1	25582
Fuji Mountain (Aut)	0	1	1	9	1	16099
Fukaura	2	0	1	18	1	23920
Fukue	2	0	1	17	1	22834
Fukui	3	0	1	18	1	24282
Fukuoka	3	0	1	18	1	24998
Fukuoka/Itazuke	3	0	1	17	1	23371
Fukushima	3	0	1	18	1	24850

Table 4 continued from previous page

Station	PV	Wind	Generator	Battery	Converter	Total NPC ($)
Fukuyama	3	0	1	18	1	23769
Fushiki	3	0	1	18	1	25346
Futenma	2	0	1	18	1	21933
Gifu	3	0	1	18	1	24744
Gifu (JASDF)	3	0	1	18	1	24744
Haboro	3	0	1	18	1	25454
Hachijojima/Omure	1	1	1	19	1	20460
Hachinohe	3	0	1	19	1	25585
Hagi	3	0	1	16	1	23228
Hakodate	3	0	1	18	1	25587
Hamada	3	0	1	18	1	23809
Hamamatsu	3	0	1	17	1	23216
Hamamatsu (JASDF)	3	0	1	17	1	23216
Hikone	3	0	1	18	1	24744
Himeji	3	0	1	18	1	23768
Hirado Island	2	0	1	20	1	21355
Hiroo	3	0	1	18	1	24713
Hiroshima	3	0	1	18	1	24084
Hita	3	0	1	17	1	23372
Hitoyoshi	3	0	1	16	1	23506
Hofu (JASDF)	3	0	1	16	1	23230
Hyakuri (JASDF)	3	0	1	17	1	24342
Lida	3	0	1	17	1	23270
Iizuka	3	0	1	17	1	23371
Irako	3	0	1	17	1	23212
Irozaki (Cape)	2	0	1	20	1	23050
Iruma (JASDF)	3	0	1	17	1	24322
Ishigakijima Island	1	1	1	10	1	22093
Ishinomaki (Point)	3	0	1	19	1	24938
Itoigawa	1	1	1	11	1	21048
Iwakuni	3	0	1	18	1	24084
Iwamizawa	3	0	1	18	1	26269
Iwojima (JMSDF)	1	1	0	8	1	18532
Izuhara	2	0	1	18	1	20794
Izumo	1	1	1	10	1	20843
Kadena (USAF/Navy)	2	0	1	18	1	21933
Kagoshima/Yoshino	3	0	1	15	1	23702
Kanazawa	3	0	1	18	1	24578
Kanoya (JMSDF)	3	0	1	17	1	23308
Kansai Internationa	1	1	1	11	1	23344
Karuizawa	3	0	1	18	1	24174
Katsuura	3	0	1	18	1	24084
Kawaguchiko	3	0	1	17	1	23467
Kitami	1	1	1	11	1	24514
Kitamiesashi	3	0	1	19	1	26286
Kobe	3	0	1	20	1	26653
Kochi	3	0	1	17	1	23989
Kofu	3	0	1	18	1	23485
Komatsu (Civ/JASDF)	3	0	1	18	1	24278
Komatsujima (JASDF)	1	1	1	9	1	20710
Kumamoto	3	0	1	16	1	23895
Kumejima	3	0	1	17	1	23290
Kumgaya	3	0	1	18	1	24463

Table 4 continued from previous page

Station	PV	Wind	Generator	Battery	Converter	Total NPC ($)
Kure	3	0	1	18	1	24084
Kushiro/Kenebetsu	3	0	1	18	1	23524
Kutchan	3	0	1	18	1	26896
Kyoto	3	0	1	18	1	24749
Maebashi	3	0	1	18	1	24442
Maizuru	3	0	1	18	1	24689
Makurazaki	3	0	1	17	1	23308
Matsue	3	0	1	18	1	24024
Matsumoto	2	0	1	20	1	22861
Matsushima (JASDF)	3	0	1	19	1	24938
Matsuyama	2	0	1	18	1	20697
Miho (Civ/JASDF)	3	0	1	18	1	24024
MinamidaitojimaIsl	2	0	1	17	1	19796
Minamitorishima	2	0	1	15	1	19075
Misawa (Npmod)	2	1	1	11	1	25576
Mishima Island	3	0	1	17	1	23468
Mito	3	0	1	19	1	26494
Miyakejima Island	2	0	1	18	1	22922
Miyako	3	0	1	18	1	24215
Miyakojima Island	1	1	1	12	1	22690
Miyakonojo	3	0	1	16	1	23970
Miyazaki	3	0	1	16	1	23971
Mombetsu	3	0	1	17	1	24317
Morioka	3	0	1	20	1	25818
Muroran/Yakumo	2	1	1	11	1	25264
Muruotomisaki (Cape)	0	1	1	10	1	17384
Mutsu	3	0	1	18	1	24157
Nagano	2	0	1	20	1	22985
Nagasaki	2	0	1	18	1	22157
Nagoya	3	0	1	18	1	24722
Nagoya (Civ/JASDF)	3	0	1	18	1	24744
Naha (Civ/JASDF)	1	1	1	10	1	20612
Naha Airport	1	1	1	11	1	21219
Nakamura	1	1	1	11	1	20940
Nakashibetsu	1	1	1	13	1	23750
Namie	1	1	1	10	1	23344
Nara	3	0	1	18	1	23453
Naze/Funchatoge	3	0	1	17	1	23409
Nemuro	1	1	1	11	1	23318
New Tokyo Intl Arpt	3	0	1	18	1	24105
Niigata	3	0	1	18	1	26045
Nikko	3	0	1	18	1	24441
Nobeoka	3	0	1	17	1	23778
Nyutabaru (JASDF)	3	0	1	17	1	23779
Obihiro	3	0	1	18	1	24713
Ofunato	3	0	1	20	1	25776
Oga	1	1	1	9	1	23314
Oita	3	0	1	17	1	24050
Okayama	3	0	1	18	1	23769
Okinoerabu/Okierabu	1	1	1	10	1	20192
Omaezaki (Cape)	1	1	1	11	1	22501
Ominato (JASDF)	3	0	1	18	1	24155
Omu	3	0	1	19	1	26266

Table 4 continued from previous page

Station	PV	Wind	Generator	Battery	Converter	Total NPC ($)
Onahama	3	0	1	17	1	24335
Osaka	3	0	1	20	1	27831
Osaka Intl/Itami	3	0	1	18	1	23453
Oshima Island	1	1	1	9	1	21001
Otaru	3	0	1	18	1	26267
Owase	3	0	1	18	1	24003
Ozuki (JMSDF)	3	0	1	16	1	23229
Rumoi	1	1	1	12	1	24476
Saga	3	0	1	17	1	23373
Saigo	2	0	1	16	1	19627
Sakai	3	0	1	18	1	24024
sakata	3	0	1	18	1	24953
Sapporo	3	0	1	19	1	24915
Sasebo	2	0	1	20	1	21355
Sendai	3	0	1	19	1	24937
Shimizu/Ashizuri	2	0	1	19	1	22522
Shimofusa (JMSDF)	3	0	1	18	1	24105
Shimonoseki	3	0	1	17	1	23362
Shingu	1	1	1	11	1	22020
Shinjo	3	0	1	20	1	26130
Shionomiski (Cape)	2	0	1	19	1	22824
Shirakawa	3	0	1	17	1	24853
Shizuhama (JASDF)	2	0	1	20	1	23050
Shizuoka	2	0	1	18	1	23002
Sukumo	2	0	1	18	1	21849
Sumoto	3	0	1	18	1	23768
Suttsu	3	0	1	18	1	26898
Suwa	3	0	1	18	1	24172
Tadotsu	3	0	1	18	1	23769
Takada	3	0	1	18	1	24403
Takajama	3	0	1	18	1	25346
Takamatsu	3	0	1	18	1	23650
Tanegashima Island	1	1	1	11	1	22154
Tateno	3	0	1	18	1	24223
Tateyama	2	0	1	18	1	22622
Tateyama (JMSDF)	2	0	1	18	1	22622
Tokushima	3	0	1	18	1	23768
Tokushima (JMSDF/Cv)	3	0	1	18	1	23768
Tokyo	3	0	1	19	1	28785
Tokyo Intl Airport	1	1	1	12	1	21819
Tomakomai	3	0	1	19	1	25491
Tottori	3	0	1	19	1	26493
Toyama	3	0	1	18	1	25346
Toyooka	3	0	1	18	1	24686
Tsu	3	0	1	18	1	24003
Tsuiki (JASDF)	3	0	1	17	1	23721
Tsuruga	3	0	1	18	1	24744
Tsuyama	3	0	1	18	1	24691
Ueno	3	0	1	18	1	24003
Unzendake (Mount)	3	0	1	16	1	23486
Urakawa	2	1	1	14	1	28610
Ushibuka	3	0	1	17	1	23308
Utsunomiya	3	0	1	18	1	24494

Table 4 continued from previous page

Station	PV	Wind	Generator	Battery	Converter	Total NPC ($)
Uwajima	2	0	1	18	1	20727
Wajima	2	1	1	15	1	27715
Wakamatsu	3	0	1	18	1	26055
Wakayama	3	0	1	18	1	23453
Wakkanai	1	1	1	13	1	24358
Yakushima Island	3	0	1	16	1	22931
Yamagata	3	0	1	20	1	26113
Yamaguchi	3	0	1	16	1	23230
Yokkaichi	3	0	1	18	1	24003
Yokohama	3	0	1	17	1	24306
Yokosuka	3	0	1	17	1	24305
Yokota (JASDF/USAF)	3	0	1	17	1	24304
Yonago	3	0	1	18	1	24875
Yonagunijima	1	1	1	7	1	18817

Table 4: Appendix Table 3

Station	COE ($/kWh)	Ren. Frac.	Co2 (kg/yr)	Diesel (L)	Generator (hrs)
Abashiri	0.42	0.93	143	54	174
Aburatsu	0.424	0.94	117	44	152
Aikawa	0.444	0.96	68.5	26	83
Ajiro	0.448	0.96	68.5	26	85
Akita	0.491	0.91	162	61	193
Akune	0.429	0.98	46.5	18	59
Aomori	0.437	0.92	156	59	192
Asahikawa	0.48	0.93	134	51	168
Ashiya (JASDF)	0.427	0.98	37.6	14	47
Asosan	0.434	0.97	50.5	19	63
Atsugi (Nas)	0.444	0.96	69	26	84
Chiba	0.441	0.97	51.1	19	65
Chichi Jima Bonin Is	0.383	0.96	81.1	31	100
Chichibu	0.444	0.96	69	26	84
Chitose (Jasdf)	0.466	0.95	87.8	33	101
Chitose (JASDF/Civ)	0.466	0.95	87.8	33	101
Choshi	0.382	0.97	67.4	26	100
Esashi	0.467	0.94	108	41	133
Fuji Mountain (Aut)	0.294	0.98	39.3	15	55
Fukaura	0.437	0.9	192	73	240
Fukue	0.417	0.92	159	60	201
Fukui	0.444	0.97	57	22	74
Fukuoka	0.457	0.96	84.3	32	109
Fukuoka/Itazuke	0.427	0.98	37.6	14	47
Fukushima	0.454	0.96	79.8	30	99
Fukuyama	0.434	0.98	38.5	15	48
Fushiki	0.463	0.95	97.7	37	126
Futenma	0.401	0.94	122	46	150
Gifu	0.452	0.96	75.4	29	96
Gifu (JASDF)	0.452	0.96	75.4	29	96
Haboro	0.465	0.94	108	41	127
Hachijojima/Omure	0.374	0.97	52.1	20	77
Hachinohe	0.467	0.96	85.3	32	110

Table 5 continued from previous page

Station	COE ($/kWh)	Ren. Frac.	Co2 (kg/yr)	Diesel (L)	Generator (hrs)
Hagi	0.424	0.98	36.2	14	47
Hakodate	0.468	0.94	108	41	133
Hamada	0.435	0.98	40	15	50
Hamamatsu	0.424	0.99	27.9	11	34
Hamamatsu (JASDF)	0.424	0.99	27.9	11	34
Hikone	0.452	0.96	75.4	29	96
Himeji	0.434	0.98	38.4	15	48
Hirado Island	0.39	0.97	54.4	21	68
Hiroo	0.452	0.96	72	27	94
Hiroshima	0.44	0.97	49.8	19	64
Hita	0.427	0.98	37.6	14	47
Hitoyoshi	0.429	0.98	46.5	18	59
Hofu (JASDF)	0.424	0.98	36.7	14	47
Hyakuri (JASDF)	0.445	0.96	68.4	26	83
Lida	0.425	0.98	30.6	12	37
Iizuka	0.427	0.98	37.6	14	47
Irako	0.424	0.99	27.9	11	34
Irozaki (Cape)	0.421	0.94	120	46	150
Iruma (JASDF)	0.444	0.96	69.9	27	85
Ishigakijima Island	0.404	0.96	85.1	32	121
Ishinomaki (Point)	0.456	0.97	59.7	23	79
Itoigawa	0.385	0.98	37.6	14	46
Iwakuni	0.44	0.97	49.8	19	64
Iwamizawa	0.48	0.93	137	52	166
Iwojima (JMSDF)	0.339	1	0	0	0
Izuhara	0.38	0.96	75.8	29	96
Izumo	0.381	0.98	45.3	17	68
Kadena (USAF/Navy)	0.401	0.94	122	46	150
Kagoshima/Yoshino	0.433	0.97	59.1	22	73
Kanazawa	0.444	0.97	56.5	21	74
Kanoya (JMSDF)	0.426	0.98	33.6	13	45
Kansai Internationa	0.427	0.94	120	46	152
Karuizawa	0.442	0.97	52	20	69
Katsuura	0.44	0.97	49.8	19	64
Kawaguchiko	0.429	0.98	36.1	14	47
Kitami	0.448	0.91	168	64	217
Kitamiesashi	0.48	0.94	115	44	142
Kobe	0.487	0.94	107	41	133
Kochi	0.438	0.97	55.7	21	73
Kofu	0.429	0.99	27.9	11	34
Komatsu (Civ/JASDF)	0.444	0.97	56.5	21	74
Komatsujima (JASDF)	0.378	0.97	61.6	23	87
Kumamoto	0.437	0.97	59.2	22	75
Kumejima	0.426	0.96	42.6	16	51
Kumgaya	0.447	0.97	65	25	82
Kure	0.44	0.97	49.8	19	64
Kushiro/Kenebetsu	0.43	0.98	29.2	11	36
Kutchan	0.491	0.92	158	60	199
Kyoto	0.452	0.96	74.5	28	97
Maebashi	0.447	0.97	64.1	24	81
Maizuru	0.451	0.96	72.4	27	94
Makurazaki	0.426	0.98	33.6	13	45
Matsue	0.439	0.98	46.2	18	62

Table 5 continued from previous page

Station	COE ($/kWh)	Ren. Frac.	Co2 (kg/yr)	Diesel (L)	Generator (hrs)
Matsumoto	0.418	0.94	110	42	143
Matsushima (JASDF)	0.456	0.97	59.7	23	79
Matsuyama	0.378	0.96	72.4	28	91
Miho (Civ/JASDF)	0.439	0.98	46.2	18	62
MinamidaitojimaIsl	0.362	0.98	46.8	18	62
Minamitorishima	0.349	0.99	25.6	10	30
Misawa (Npmod)	0.467	0.97	53.5	20	72
Mishima Island	0.429	0.98	36.1	14	47
Mito	0.484	0.94	122	46	153
Miyakejima Island	0.419	0.92	154	59	198
Miyako	0.442	0.97	55.4	21	68
Miyakojima Island	0.415	0.96	77	29	100
Miyakonojo	0.438	0.97	64.4	24	78
Miyazaki	0.438	0.97	64.4	24	78
Mombetsu	0.444	0.97	64.9	25	80
Morioka	0.472	0.96	76.5	29	91
Muroran/Yakumo	0.462	0.98	46	17	60
Muruotomisaki (Cape)	0.318	0.97	64.5	24	92
Mutsu	0.441	0.97	53.2	20	67
Nagano	0.42	0.94	118	45	147
Nagasaki	0.405	0.93	129	49	162
Nagoya	0.452	0.96	74.5	28	95
Nagoya (Civ/JASDF)	0.452	0.96	75.4	29	96
Naha (Civ/JASDF)	0.377	0.98	38.9	15	55
Naha Airport	0.388	0.98	41.9	16	56
Nakamura	0.383	0.99	29	11	44
Nakashibetsu	0.434	0.95	98.9	38	122
Namie	0.427	0.93	144	55	188
Nara	0.429	0.99	25.9	10	33
Naze/Funchatoge	0.428	0.98	42.4	16	51
Nemuro	0.408	0.96	83.5	32	110
New Tokyo Intl Arpt	0.44	0.97	50.6	19	65
Niigata	0.476	0.94	124	47	157
Nikko	0.447	0.97	64.1	24	81
Nobeoka	0.434	0.97	50.5	19	63
Nyutabaru (JASDF)	0.434	0.97	50.5	19	63
Obihiro	0.452	0.96	72	27	94
Ofunato	0.471	0.96	74.7	28	89
Oga	0.426	0.93	147	56	204
Oita	0.439	0.97	61.3	23	78
Okayama	0.434	0.98	38.5	15	48
Okinoerabu/Okierabu	0.369	0.99	24.8	9	33
Omaezaki (Cape)	0.411	0.95	90.5	34	119
Ominato (JASDF)	0.441	0.97	53.2	20	67
Omu	0.48	0.94	1143	43	141
Onahama	0.445	0.96	68.4	26	83
Osaka	0.509	0.92	154	58	189
Osaka Intl/Itami	0.429	0.99	25.9	10	33
Oshima Island	0.384	0.97	66.5	25	96
Otaru	0.48	0.93	137	52	166
Owase	0.439	0.98	46.7	18	60
Ozuki (JMSDF)	0.424	0.98	36.7	14	47
Rumoi	0.447	0.92	148	56	185

Table 5 continued from previous page

Station	COE ($/kWh)	Ren. Frac.	Co2 (kg/yr)	Diesel (L)	Generator (hrs)
Saga	0.427	0.98	37.6	14	47
Saigo	0.359	0.98	44.5	17	58
Sakai	0.439	0.98	46.2	18	62
sakata	0.456	0.96	83.7	32	106
Sapporo	0.455	0.97	64.1	24	74
Sasebo	0.39	0.97	54.4	21	68
Sendai	0.456	0.97	63.7	24	76
Shimizu/Ashizuri	0.412	0.93	124	47	150
Shimofusa (JMSDF)	0.44	0.97	50.6	19	65
Shimonoseki	0.427	0.98	37	14	47
Shingu	0.402	0.96	72.8	28	95
Shinjo	0.477	0.95	87.3	33	107
Shionomiski (Cape)	0.417	0.93	135	51	165
Shirakawa	0.454	0.96	80.1	30	99
Shizuhama (JASDF)	0.421	0.94	120	46	150
Shizuoka	0.42	0.92	159	61	203
Sukumo	0.399	0.94	118	45	146
Sumoto	0.434	0.98	38.4	15	48
Suttsu	0.491	0.92	159	60	199
Suwa	0.442	0.97	52.1	20	69
Tadotsu	0.434	0.98	38.5	15	48
Takada	0.446	0.97	62.8	24	79
Takajama	0.463	0.95	97.7	37	126
Takamatsu	0.432	0.98	32.9	12	43
Tanegashima Island	0.405	0.96	74.5	28	104
Tateno	0.443	0.97	53.1	20	70
Tateyama	0.413	0.93	142	54	184
Tateyama (JMSDF)	0.413	0.93	142	54	184
Tokushima	0.434	0.98	38.4	15	48
Tokushima (JMSDF/Cv)	0.434	0.98	38.4	15	48
Tokyo	0.526	0.89	210	80	265
Tokyo Intl Airport	0.399	0.98	42.9	16	58
Tomakomai	0.466	0.95	87.8	33	101
Tottori	0.484	0.94	122	46	153
Toyama	0.463	0.95	97.7	37	126
Toyooka	0.451	0.96	72	27	94
Tsu	0.439	0.98	46.7	18	60
Tsuiki (JASDF)	0.433	0.98	47.7	18	61
Tsuruga	0.452	0.96	75.4	29	96
Tsuyama	0.451	0.96	72.5	28	94
Ueno	0.439	0.98	46.7	18	60
Unzendake (Mount)	0.429	0.98	46.1	18	58
Urakawa	0.523	0.94	114	43	137
Ushibuka	0.426	0.98	33.6	13	45
Utsunomiya	0.448	0.97	66.9	25	83
Uwajima	0.379	0.96	74.2	28	92
Wajima	0.506	0.97	55.3	21	68
Wakamatsu	0.476	0.94	125	47	157
Wakayama	0.429	0.99	25.9	10	33
Wakkanai	0.445	0.94	120	46	153
Yakushima Island	0.419	0.99	27.4	10	32
Yamagata	0.477	0.95	86.9	33	106
Yamaguchi	0.424	0.98	36.7	14	47

Table 5 continued from previous page

Station	COE ($/kWh)	Ren. Frac.	Co2 (kg/yr)	Diesel (L)	Generator (hrs)
Yokkaichi	0.439	0.98	46.7	18	60
Yokohama	0.444	0.96	69	26	84
Yokosuka	0.444	0.96	69	26	84
Yokota (JASDF/USAF)	0.444	0.96	69	26	84
Yonago	0.455	0.96	82.4	31	101
Yonagunijima	0.344	0.99	30.9	12	53

Table 5: Appendix Table 4

Station	Fuji Mountain (Aut)		Iwojima(JMSDF)		Minamitorishima		Tokyo	
Components	Wind turbin	Generator	PV Panel	Wind turbine	PV Panel	Generator	PV Panel	PV Panel
Jan.	0.39	0	0.18	0.4	0.33	0	0.37	0
Feb.	0.41	0	0.2	0.41	0.39	0	0.38	0
Mar.	0.45	0.01	0.22	0.4	0.43	0.02	0.39	0.04
Apr.	0.48	0	0.22	0.37	0.44	0	0.39	0.02
May	0.5	0	0.21	0.37	0.44	0	0.4	0.01
Jun.	0.5	0	0.23	0.25	0.45	0	0.34	0.03
Jul.	0.48	0	0.23	0.27	0.42	0	0.39	0.01
Aug.	0.41	0.03	0.22	0.4	0.42	0.01	0.41	0.02
Sep.	0.49	0	0.24	0.4	0.44	0	0.34	0.06
Oct.	0.5	0	0.23	0.37	0.42	0	0.29	0.04
Nov.	0.47	0	0.19	0.46	0.39	0	0.34	0.02
Dec.	0.41	0	0.17	0.46	0.33	0	0.33	0.02
Production (kwh/yr)	4049	42	1.89	3.368	3.62	29	3.23	234
Excess electricity (kwh/yr)	1573		2743		1015		815	
Hours of operation (hr/yr)	7.71	55	4.39	7.39	4.37	30	4.35	265
Battery Losses (kwh/yr)	115		114		232		228	
Inverter/Rectifier Losses (kwh/yr)	239.4		240		239.3		233.25	

Table 6: Appendix Table 5

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