[STRATEGY FOR SALINITY GRADIENT ENERGY HARVESTING IN JAPAN]

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Overview

At estuaries around the world, freshwater flows out of rivers and mixes with seawater. During this process, an enormous amount of chemical energy is dissipated as heat near the estuaries. Is it possible to convert this energy, which is lost every day, into electricity and make effective use of it? What makes this possible is a power generation technology called Salinity Gradient Power generation (SGP).

SGP generation uses the osmotic pressure difference between freshwater and seawater; it manipulates the flow of water molecules and ions, and then converts that flow into electrical energy. SGP generation enables us to collect electric energy at any time of the day near estuaries, regardless of the weather or time of day. Furthermore, the energy obtained, called Salinity Gradient Energy (SGE), is renewable since there is little concern that the resource will be depleted in the future due to mass consumption. Because of this promising outlook, the potential amount of SGE has been previously estimated for various estuaries around the world [1]. A common idea when considering the SGE potential is that the more river water available, the more electrical power can be generated. From this perspective, Japan's coastal areas will be geographically well suited for SGP generation. In Japan, about three-quarters land area is covered by forests and mountains, and there are abundant water sources in each region. In addition, Japan's annual precipitation is nearly twice the world average, despite its small land area. Furthermore, many rivers in Japan are shorter and have steeper gradients than those on the continent. Given these conditions, it can be inferred that Japanese rivers have sufficient flow capacity for SGP generation. To the authors' knowledge, however, no previous study has quantitatively calculated the SGE potential of Japan's coastal areas.

In this study, we analysed the domestic stock of SGE for the first time in this field, focusing on the major estuaries in Japan. The results show that areas with high SGP values are concentrated on the northeast coast. We also found that the SGE potential is equal to or higher than those generated from other renewable energy sources that are operating in the country. Our results indicate that SGP generation can be combined with other renewable energies as a complementary to compensate for the weaknesses of solar and wind power generation.

Methods

The upper limit of SGE that can be extracted from the mixed solution per unit time can be obtained using the formula given in Ref. [2]. The values of geographical data and water quality data needed for the calculation (e.g., river flow rate, water temperature, and water salinity) were picked up from databases published by public institutions in Japan. The noteworthy points to keep in mind when considering water withdrawal from rivers is that, when the SGP plant is actually operated, only a portion of the total river flow is allowed to be taken to the plant in order to control adverse effects on the surrounding environment caused by the power plant installation. We thus assumed that only 10% of the river flow is used for SGP generation, with the 90% remaining in the river after intake. In addition, in the actual power generation process, a part of the generated energy is inevitably dissipated to the outside. Therefore, in this study, the energy conversion efficiency was assumed to be 40%, referring to the results of previous analyses [3].

Results

The left table in Figure 1 shows the top 7 and bottom 2 estuaries in Japan's first-class rivers (109 water systems in all) in terms of SGP generation [4]. The lower part of the table shows the average and total SGP values for Japan as a whole. The "Theor." in the table means the theoretical amount of electricity that can be generated when assuming 100% river flow intake and 100% energy conversion efficiency. On the other hand, "Pract." means the practical amount of electricity that can be expected when only 10% of the total river flow can be withdrawn and the energy

conversion efficiency is limited to be 40%. The calculation results indicate that the SGP generation from Japan's major rivers can be useful as a medium-scale power supply source to meet the electricity demand in each area near the estuaries.

The map in the middle of Figure 1 shows the locations of the top 7 estuaries that would produce particularly large outputs [4]. It follows that 3 of the top 7 estuaries with the highest SGP values (Shinano, Agano, and Mogami rivers) are concentrated in the northern part of the Japan Sea coast. This biased distribution may be attributed to that the annual precipitation in this region is relatively higher than in other regions, resulting in higher river flow rate in the estuary area. The results shown in Figure 1 should provide basic information for considering suitable sites for the construction of SGP generation facilities in Japan in the future.

The table on the right of Figure 1 compares the availability of SGE with those obtained from other power generation methods [4]. For existing methods (other than SGP), the power generation capacity (i.e., the maximum amount of power that a generator can produce when running at full performance) were presented. The two left-hand columns show the average and maximum amount of electricity generated per power plant. The rightmost column shows the total amount of electricity that could be generated by all power plants in the country. An important finding from the table is that the amount of SGE per power plant is not significantly less than the amount of electricity generated by solar, wind, and other renewable energy sources. This result suggests that SGP generation can be used as a major renewable energy resource to support the energy mix in the future. In fact, solar and wind power have the disadvantage that their generation depends on the weather and time of day. Therefore, the use of SGP generation to compensate for this weakness may increase Japan's energy supply rate from renewable energy sources. In addition to these results, we are currently studying the economic feasibility of SGP in Japan from the viewpoint of levelized cost of energy and will present the results at the presentation.

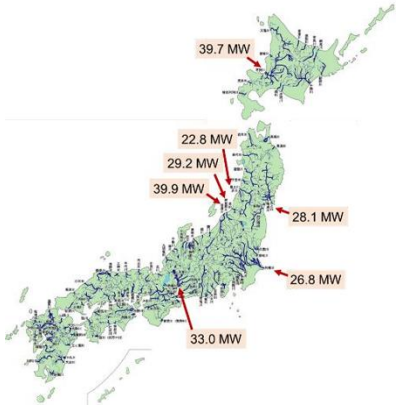
Conclusions

In this study, we quantified the extractable SGE from each of 109 major rivers in Japan using the publicly available river discharge database. The results show that areas with high SGE values are concentrated on the Sea of Japan side. It was also found that SGP generation can be expected to have similar or higher values than other renewable energy generation in operation in Japan. This result means that SGP generation can be combined with solar and wind power generation as a complementary energy source. We hope that this first quantitative analysis on SGE will provide clues for the development of new energy sources in Japan.

References

[1] O. A. Alvarez-Silva, A. F. Osorio, C. Winter: Renew. Sustain. Energy Rev. 60 (2016) 1387. [2] C. Forgacs, R. N. O'Brien: Chem. Can. 31 (1979) 19. [3] T. Thorsen, T. Holt: J. Membrane Sci. 335 (2009) 103. [4] K. Watanabe, Y. Akiba, H. Ishidaira, H. Shima: Available at SSRN (https://ssrn.com/abstract=5081762).

	Theor. [MW]	Pract. [MW]
Shinano	998	39.9
Ishikari	993	39.7
Kiso	826	33.0
Agano	726	29.2
Kitakami	702	28.1
Tone	669	26.8
Mogami	570	22.8
⋮	⋮	⋮
Ave.	152	6.1
⋮		
Rokkaku	13	0.5
Doki	3	0.1
⋮	⋮	⋮
Total	**16,518**	**660.7**



	Average output [MW/plant]	Maximam output [MW/plant]	Number of plants existed	Total output in Japan [GW]
SGP (Theor.)	152	998	109	16.5
SGP (Pract.)	6	40	109	6.6
Nuclear	2,206	8,212	15	33.1
Thermal	336	5,160	467	15.6
Biomass	50	4,100	98	4.6
Hydro	28	560	1,674	49.5
Geothermal	26	112	17	0.4
Wind	13	122	356	4.6
Solar	4	258	4,724	16.4

Figure 1. (Left) SGP generation ranking of major rivers in Japan. (Middle) Distribution of the top 7 rivers. (Right) Comparison of the power output obtained using different power generation methods in Japan.