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Case Report

Realize 100% Renewable Energy by Sailing Mega-Solar Rafts in Low-Latitude Pacific Ocean

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Abstract: Besides offshore wind power, which is a major target of renewable energy development worldwide, huge sunshine energy affluent in the low-latitude Pacific Ocean may be captured with a reasonable economy by mega-PV solar module rafts always sailing slowly on open seas. Maritime conditions there are very favorable in vast seas with rich sunshine and mild wind/wave conditions with little risk of tropical storms. According to international maritime laws, the open seas are considered open to peaceful sailing of mega-solar rafts, though their impacts on other vessels should be minimized. A crude feasibility study indicates that it is not a baseless dream but worth challenging by integrating already available basic technologies, upgrading, and upscaling. With due international cooperation including island nations, it will contribute to dramatically increasing renewable energy resources for human-being along with off-shore wind power.

***Keywords*:** low-latitude Pacific Ocean, mega-solar module raft, sunshine-energy density, energy transportation

1. Introduction

The Japanese Government recently declared to complete carbon-neutralization of the country by 2050. However, no realistic scenario toward that goal has yet been secured. With its limited land areas inhabited by more than a hundred million people, Japan cannot realize this target only by land-based natural energies such as hydraulic, geothermal, solar, and wind, even with the aid of reoperations of existing nuclear power stations. The most plausible strategy the government will take is offshore wind power similar to many other nations in the world. A great many offshore wind farms have already been developed in northern European countries like Denmark, the UK, and Germany in these decades. They are all fixed-bottom types with their foundations constructed directly on the sea floor, where the water depth cannot be greater than 50 m at the deepest. Unfortunately, sea floors around the Japanese islands tend to get deeper in a short offshore distance, restricting the potential capacity of the fixed-bottom type.

Hence, a floating type for deeper seas is suitable, in which the wind turbine is mounted on the float moored and anchored to the sea floor. The UK is proud of this offshore technology as a front-runner in R & D making the most of the experience in the North Sea oil/gas projects and planning to demonstrate the technology by getting them matured in a few years through a couple of test-site operations [1]. The Japanese government is looking forward to the floating type of wind power as a promising renewable energy because large sea areas may be able to be chosen as their viable sites.

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However, a commercial operation of floating wind power has not yet begun even in Europe. In Asian regions like Japan and Taiwan, where natural environments are more hostile with severe typhoons, high seismicity, and tsunami, considerable technical challenges will have to be overcome before the power system can become dependable as a major player. A couple of test sites have already been selected and experimental floating wind power projects are tested for years, though their clear technical perspective has not yet been established publicly. Furthermore, fishing industries in Japan have historically had strong voices in using coastal oceans, which may impose another constraint on the off-shore wind power.

Thus, it seems too optimistic to believe that we can depend exclusively on off-shore wind power pioneered in north Europe [1] to meet the huge demand for renewable energy in Japan. Instead, other renewable energy potentials suitable to our particular environments in medium or low latitude east Asian countries have to be explored, where solar energy seems to be more advantageous to the wind.

In this respect, we have had a research committee in 2012-2014 wherein an innovative off-shore solar energy project was proposed that could bring huge renewable energy by gigantic PV mega-solar rafts in the low-latitude Pacific Ocean [2] as illustrated in Figure 1. It seems very strange that, currently, ocean energy focuses too much on wind power even in Asian countries, where the PV solar-module may potentially generate 1.5 times more energy than wind turbines per area according to some specialists e.g. [3].

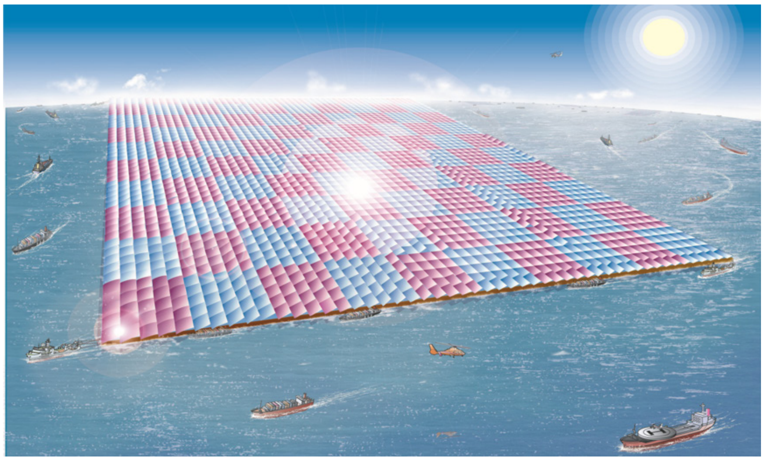

Figure 1. 5 km by 5 km Mega-Solar Raft fleet sailing in the low-latitude Pacific Ocean [2], [3]

In the proposed project, despite apparent literature gaps, huge sunshine energy affluent in the low-latitude Pacific Ocean may be able to be captured with a reasonable economy by the mega-solar module raft sailing slowly as a fleet together with accompanied vessels in pursuing optimum sunshine and favorable weather in international open seas. In this article, the project is reviewed again in terms of natural/environmental/law issues, technical challenges, and feasibility in order to emphasize its great potential to realize huge renewable energy for human beings besides offshore wind power.

2. Sailing mega-solar rafts in low-latitude pacific ocean

In recent years, floating-type PV solar power has been deployed in protected calm sea water such as in Singapore [4]. In the Netherlands and other European countries, they are under development to boost the capacity of offshore wind power and tested on a small scale in rough waves of the North Sea [5]. Some of them are integrated with fish cultivation floats covered by solar PV modules of thin/flexible type [6]. In the offshore mega-solar projects so far proposed worldwide, however, floats are moored in fixed points and have to be designed to survive severe stormy weather. In the presented project, in good contrast, the gigantic raft is always sailing at a low speed by wind and sea current to be able to select optimal sunshine and favorable weather conditions for generating electricity.

There is no doubt that any countries are authenticated by the International Maritime Law to make peaceful sailing on international open seas, while renewable energy is exploited for commercial purposes. Hence, it is considered possible to share a consensus in international forums such as IMO (International Maritime Organization) on how to accept such innovative raft sailing for solar power generation, the first of its kind on international open seas, and in exclusive economic zones (EEZ) of many countries if acceptable, by minimizing the impact on conventional sea-traffics and other human activities there.

If a gigantic mega-solar raft of 5 km square is considered, for example, the electric energy generated only during daylight hours can be equivalent to 1 GW nuclear power stations working 24 h (capacity factor 100%), by assuming daily sunshine energy per unit area 8 kWh/m^2 and energy conversion efficiency 12% (conservative value of silicone solar module today).

In most of the low-latitude Pacific Ocean, according to NASA satellite data [7] shown in Figure 2, the annual average of daily sunshine energy exceeds 6.0 kWh/m^2. The highest can reach 6.5-7.0 kWh/m^2 in a wide area from the equator to 15° south expanding as vast as the Australian continent. Hence, it seems possible for the mobile raft to make an energy-saving slow-speed sailing to pursue seasonally optimal sunshine and attain 8.0 kWh/m^2 [2] (more than twice the average in Japan).

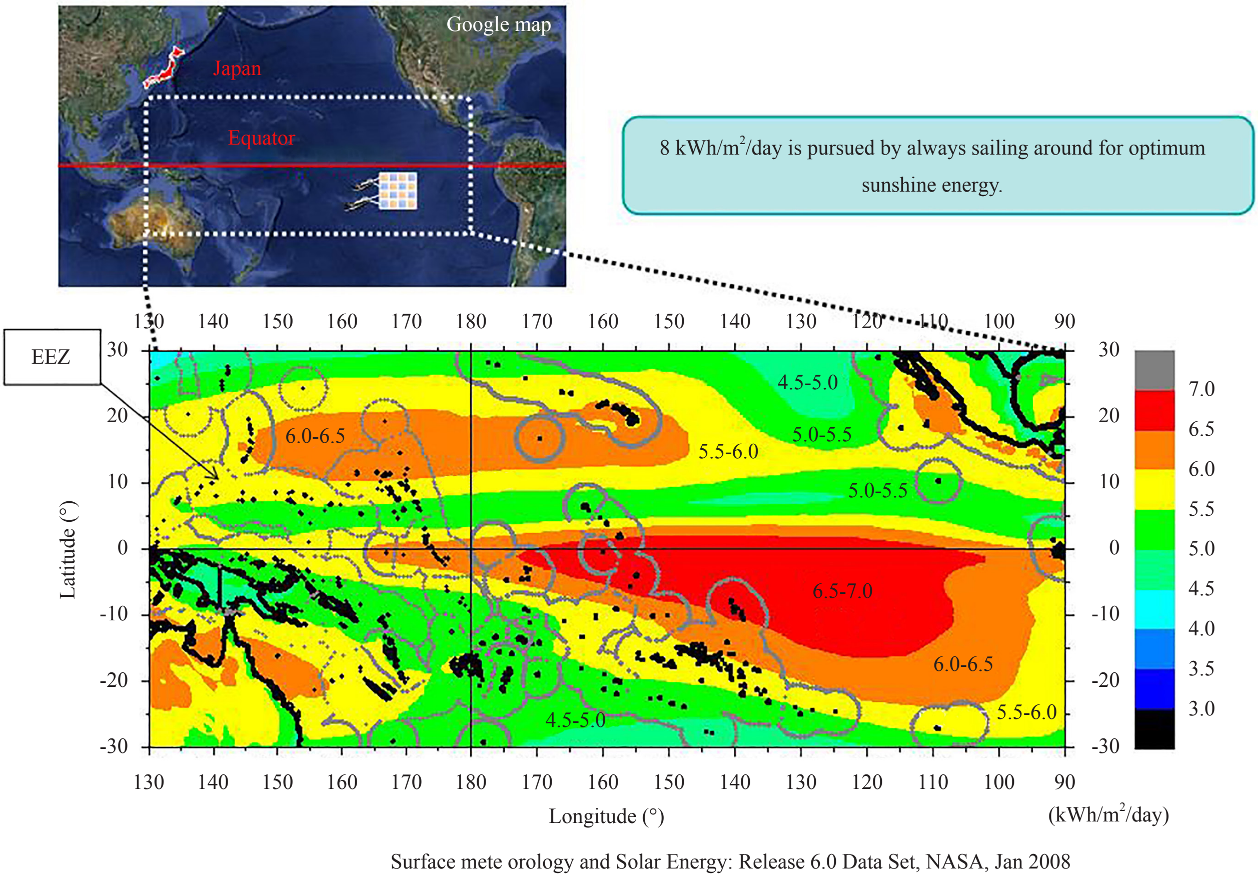

Figure 2. Daily sunshine energy on the annual average in the low-latitude Pacific Ocean where Mega-Solar Raft sailing around pursuing better sunshine [2], [7]

The wind there is very mild and stable with an annually averaged wind speed of 3-7 m/s according to NASA [7] and JMA [8], distinctly lower than in high-latitude oceans, and also wind direction is stationary all year round. The waves are not rough throughout the year, 1-2 m high on an annual average in low-latitude Pacific according to JMA data [8] unlike middle/high latitude, though the solar module raft will be designed operational in much higher waves.

The greatest risk to this mega-solar raft system, tropical depressions, typhoons, hurricanes, or cyclones, cannot be ignored. In Figure 3, tropical depressions observed in 1985-2005 are plotted in the bottom chart in terms of their origin and travel routes [9], which can be separated into three regions. However, it is interesting to note compared with the same sunshine energy map shown again in the top chart of the figure that there are two wide areas completely free from the risk. One is overlapping with the area of the highest sunshine energy where exceptionally cold sea current originated from Antarctica makes stable high atmospheric pressure zone of good weather without the risk of a storm. Another is some degrees north/south in latitude from the equator where tropical depressions cannot be born theoretically because of the Coriolis effect. In other areas, the risk tends to increase, though not so severe as in the medium-latitude Pacific. Though in-advance evacuation is vital for safe operations there, it may well be expected that rapidly advancing meteorological observation technologies will enable reliable predictions of the tropical storms in a month ahead in near future.

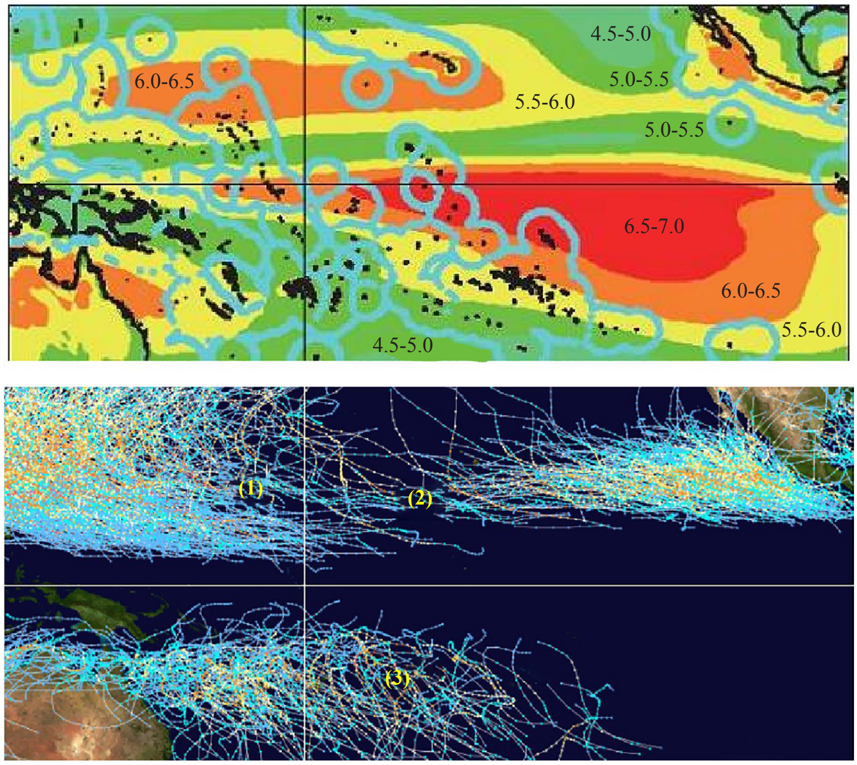

Figure 3. Traces of traveling routes of tropical depressions (1985-2005) (bottom) [9] compared with sunshine energy density (top) in the same low-latitude Pacific Ocean

As for another serious natural disaster, a tsunami, the effect may not be critical to this energy system as long as the fleet stays remotely from shallow coastal areas. Also, there is no need for an earthquake design because major vibration energy cannot propagate in seawater.

3. Environment/law-issues

There may not be environmental issues too hard to overcome for operating the fleet. The most serious will be how to protect seawater from potential pollution during accidents and normal operations. As for the effects on marine lives, it may be fortunate that the mega-solar raft has only a minimal impact on them because of its nonstop mobility compared to those that are stationary at a fixed location. Also, note that tropical oceans are less eutrophic than in high-latitude without significant adhesion of marine life to the raft and other facilities exposed to seawater.

In international maritime law, international open seas are open to anybody, though due care should be paid to other sea traffics and nearby countries. How to accept solar-module rafts, the first of their kind, in conventional sea traffics in terms of safety and functional requirements, has to be discussed and agreed upon by international organizations such as IMO. In such discussions, the significance of epoch-making use of huge renewable ocean energy has to be commonly shared in order to deregulate existing rules on conventional sea traffics. It may at least be required to always signal this location of a solar raft and announce the sailing route well in advance to other sea traffics. It may well be expected that the most advanced technologies will make it possible to control the wind-sailing route and precisely predict it. In this respect, it is noted that most commercial ships actually pass in high latitudes [10], leaving the low-latitude Pacific Ocean free from heavy sea traffic, very fortunately, as clearly indicated in Figure 4.

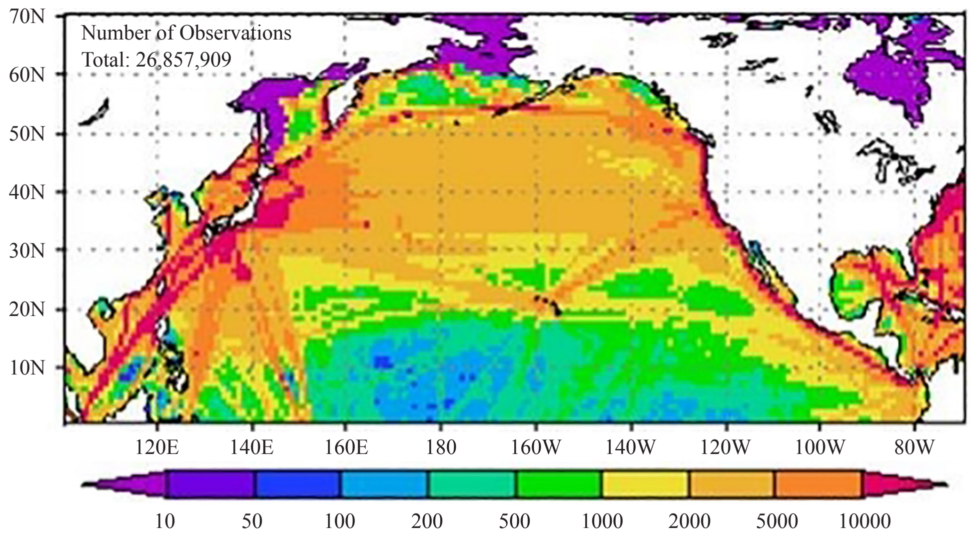

Figure 4. The density of shipping routes is more often followed by commercial vessels in the Northern Pacific Ocean where reddish colors mean higher density than blueish [10]

4. Major technological challenges

Innovative Raft

- Light-weight & simplified structure for low-cost, easy transportation & in situ fabrication
- Energy-saving sail by wind and sea-current
- Easy operation, maintenance & repair aided by Al

Solar Module & Energy Collection

- Thin & Flexible solar module with high energy efficiency
- Low-cost solar module production printed on sail cloths
- Efficient energy collection system with durability

Energy Transportation

Option-1:
- Huge electrolysis converting electricity to hydrogen
- hydrogenation into MCH & Shuttle by oil tankers

Option-2:
- Huge packages of EV-batteries transported by ships with minimal energy conversion loss

Figure 5. Three major technologies to realize the energy system

In our scenario, to realize this energy system contributing to the carbon-neutral initiative by 2050, the three major technologies as listed in Figure 5 have to be challenged to be practically mature in 30 years: a) Innovative raft system, b) Solar module system, and c) Energy transportation.

4.1 *Innovative raft system*

The 5 km by 5 km giant raft typically consists of 2,500 units of 100 m square, each of them further comprising 16 sub-units of 25 m square, on which 4 solar modules lie. All of the units/sub-units are connected by universal joints to allow free deflection following wave motions. The gigantic raft is designed to be able to sail intact as a whole assembly according to long-term weather forecast basically by wind and sea-current using sails and rudders aided by AI/IoT technology. The rafts are designed to survive high wave/strong wind conditions, though they do not have to prepare for the devastating impacts of tropical depressions, which can be evaded in advance as already mentioned.

Raft materials are either steel or HDPE (High-Density Polyethylene) or their combination. Each sub-unit (25 m × 25 m) consisting of floats, sailing poles & solar modules weighs 81 tf for steel and 17.6 tf for HDPE [11]. Sub-units are prefabricated in Japan and shipped as cargo to the low-latitude Pacific and joined together in the calm sea or on nearby islands.

4.2 *Solar modules*

Solar modules, different from silicone-type, thin, light-weight, and flexible (CIGS or Perovskite type), may be suitable. The modules are installed on the top of the raft sub-units and can be functional even in rough waves because of the flexibility and high tensile strength, unlike the conventional silicone-type rigid thick modules, presumably weaker to outer stresses. In Norway, thin flexible PV solar modules are presumably installed in a fish-cultivating HDPE float and tested in the ocean [6].

The energy-conversion efficiency in the solar module is expected to be around 20% in the near future, and low-cost manufacturing technology of the thin module integrated with sail cloths has to be developed. A large number of solar modules (160 thousand) covering all over the raft and the associated energy collection systems should be long-term durable in a salt-water environment. AI-based labor-saving technologies have to be developed to monitor, maintain, and repair a great number of solar modules and power collection systems.

4.3 *Energy transportation*

How to transport the huge energy efficiently over long distances from the low-latitude Pacific to Japan is another big technical challenge. There may be two options.

Option No.1 is to transform the generated electricity into hydrogen gas by water-electrolysis and shuttled through either in the form of liquefied hydrogen or other chemicals such as MCH (Methylcyclohexane) by huge tankers [11]. Electrolysis is commonly used for this option, though a measurable energy loss of 18% is incurred inevitably. Further great energy loss of 25 to 30% occurs in the above-mentioned process of cryogenic H_2 liquefaction or MCH-reactions even if another huge loss in returning H_2 to electricity again is not considered.

Option No.2 is to transport the electricity as it is by using a myriad of high energy-density EV batteries packaged in special racks to be recharged in the mega-solar raft. This option has a great advantage over the former because the energy loss in charge/discharge is only around 10%, though the EV battery modules have to be standardized to be plugged into the racks.

5. Feasibility evaluation

In comparison with the floating wind power systems currently under development worldwide, this sailing solar power may look far unrealistic and more challenging. However, the wind power project in Japan to construct thousands of 10-20 MW floating wind farms of 200-300 m high above sea level in a few decades are also never so easy. It also seems very challenging in ocean engineering ever experience, though this challenge has already started in many parts of the world, pioneered by European countries.

While the sailing solar module raft concept has never been proposed before and sounds like a dream because of obvious literature gaps, most of the bases of pertinent technologies to be challenged are already available actually as briefly outlined above. What is needed is to integrate those individual basic technologies together while scaling up their capacity, raising the efficiency for better performance, and minimizing cost in the next 30 years. Another key requirement to realize this concept is to form an international consensus in IMO to accept wind-sailing huge rafts in the low latitude Pacific Ocean with due regulations for minimizing the impacts on other sea traffic and ocean environments.

The economic feasibility has been estimated in the research activity during 2012-2014 on the 5 km by 5 km mega-solar raft by roughly extrapolating the current state of technologies [11], [12]. Hydrogen was used for energy transportation, where MCH is shuttled by large oil tankers once every two weeks for an average distance of 8,200 km from the central Pacific to Japan.

It has been indicated that subsidizing the market price of hydrogen by 50% will make it economically feasible, though a much more cost-cutting effort is required to be viable for market-competitive hydrogen prices [11], [12]. In particular, the giant raft must be much more innovative, and free from conventional float design concepts for drastic cost reduction. Chemical plants needed for hydrogen energy transportation by MCH, such as electrolysis and hydrogenation, are also very costly and have to be drastically economized by incorporating advanced technology, scaling-up, and mass production effects. In this context, if the above-mentioned battery transport becomes possible instead of hydrogen, considerable improvement in the economy would surely be achieved.

6. Concluding remarks

• The mega-solar raft fleet system in the low-latitude Pacific Ocean is never a dream but a promising target for a huge volume of renewable energy on earth other than offshore wind power.

• Though multiple steps for validation will be needed to reach the gigantic 1 GW system eventually, it seems possible to realize a smaller capacity mega-solar module raft to operate in the low-latitude Pacific by 2050, because the basic technologies are already in our hands.

• Also note that such an innovative green energy initiative where international multidisciplinary cooperation is critical will surely create next-generation disciplines in science & technology, new markets in business, and job opportunities not only in Japan but all over the world.

• Thus, besides offshore wind power, we may be able to have another option of huge renewable energy and dramatically boost renewable energy supply not only in Japan but in many other countries with small land areas, large populations, and large energy demand.

• As a political issue, one may wonder if such a green-energy initiative in the low-latitude Pacific Ocean may be able to coexist with the current US-China power confrontation right there. Because of that, however, it is really meaningful from a quite different perspective of world peace to start this initiative in cooperation firstly with Pacific Island nations as well as with many other countries sharing the same interest.

• Time will surely come sooner or later when developing countries have sufficiently developed and start to demand as much energy as already-developed countries. Then, abundant sunshine energy in the low-latitude Pacific Ocean will be targeted by many countries as the last resort for huge renewable energy on earth. To prepare for that, Japan is the right country in the right position to take the first step toward this endeavor in cooperation with many other countries, including Pacific island nations.

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Conflict of interest

The authors declare no conflicts of interest.

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