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Post-disaster resilience of a 100% renewable energy system in Japan

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ABSTRACT

Following the 2011 Fukushima nuclear disaster, Japan is having to re-design its energy policy. With the danger of nuclear power in an earthquake-prone country exposed, renewable energies are being seen as a potential alternative. An assessment of the feasibility of a 100% renewable energy electricity system in Japan by the year 2030 was shown to be able to achieve a higher level of electricity resilience. The assessment is based on a simulation of the hourly future electricity production based on wind and solar meteorological data, that can cope with the estimated future hourly electricity demand in Japan for the year 2030. Such as system would use pump-up storage and electric batteries to balance the daily fluctuations in supply and demand, though the most important challenge of the system would be providing sufficient electricity to meet the summer demand peak. These findings have import implications at the policy making level, as it shows that the Japanese electricity generation system is technically able to increase the share of renewables up to 100%, guaranteeing a stable and reliable supply.

1. Introduction

On March 11, 2011 (hereafter 3/11), a large earthquake of magnitude 9.0 on the Richter scale offshore the northeast coast of Japan generated a major tsunami which devastated large parts of Japan's north-eastern coastline, inundating over 400 km^2 of land, and causing large numbers of casualties. On the Sendai Plain, the maximum inundation height was 19.5 m, and the tsunami propagated as a bore for around 4–5 km inland. The maximum run-up height was 40.4 m, making it the third world's large scale tsunami in the last ten years [1]. Buildings, including many well-engineered reinforced concrete structures, suffered extensive damage, with numerous ships left stranded inland [2]. Coastal protection works such as dikes, tsunami walls, breakwaters and coastal forests also suffered heavy or catastrophic damage, prompting a re-thinking of how these structures should be designed in the future [3,4]. Historically, this was one of the worst tsunamis that affected Japan since records began. In fact, the 2011 *Great Eastern Japan Earthquake and Tsunami* has been described as a one in 1000 years event, resembling thus the Jogan Tsunami which occurred in A.D. 869 [5].

The tsunami also overcame protection defences at the Fukushima Dai-ichi nuclear power plan (NPP), bringing down the emergency cool down systems and resulting in the release of large quantity of radioactive materials into natural ecosystems. Following the earthquake and nuclear accident nearly 30% of the electricity supply was put out of service. Although many units will eventually be brought back into operation, none of the 50 nuclear power plants were operational (as of January 2014), since the Oi NPP Nos. 3 and 4 reactors were shut down for maintenance last September 2013. Recently, the newly created Nuclear Regulation Authority (*Genshiryoku Kisei Iinkai*, NRA) has been conducting safety inspections and assessments of natural disaster robustness of existing nuclear power reactors. Work is currently underway to improve the natural disaster countermeasures of several of these power stations, such as the erection of tsunami walls of increased height and waterproofing the doors at Hamaoka power station. However, it is still not clear if these countermeasures can really protect against large low frequency events [4], especially given the potential cost of the measures (see Fig. 1). Thus, how many nuclear reactors can be brought back online is uncertain at the time of writing, especially given present social concerns about nuclear power safety. A recent opinion poll revealed that 70% of Japanese

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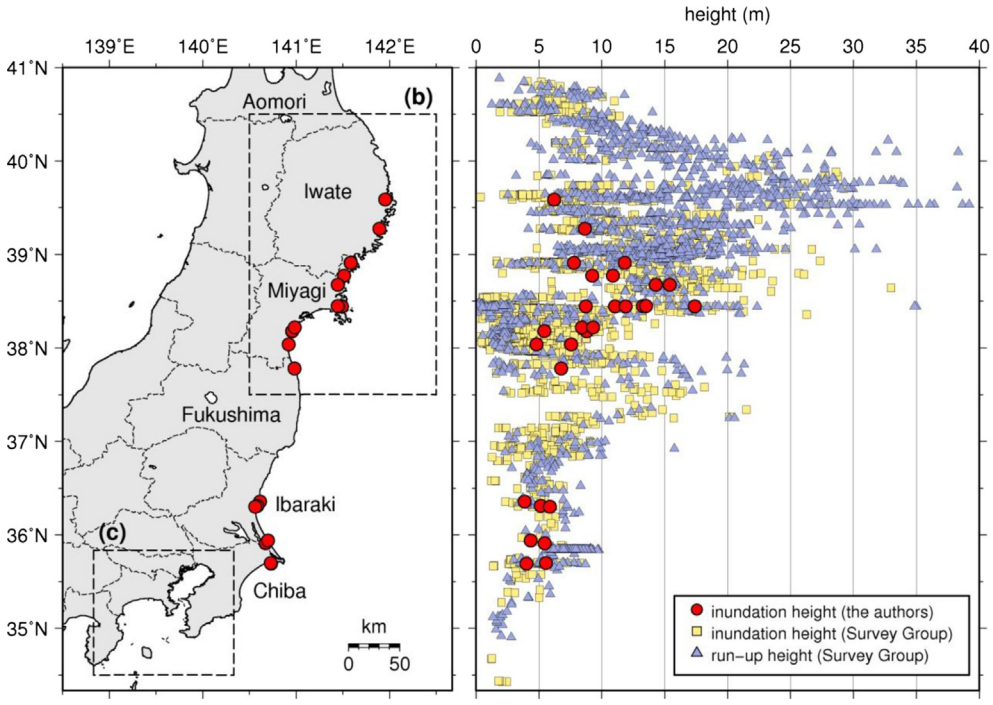

Fig. 1. Tsunami inundation and run-up heights during the 2011 *Great Eastern Japan Earthquake and Tsunami* [1].

are in favour of a nuclear power phase out, and 60% approves the decommission of all units before 2030 [6].

Tsunamis and earthquakes, however, are not the only types of natural disasters to affect Japan. The country is also frequently affected by tropical cyclones, and it is feared that these atmospheric phenomena will increase in the future. Tropical cyclones need high surface sea temperatures to form (typically at temperatures of over 26 °C), as they use the heat from the evaporation of sea water to maintain or increase their strength, and it would appear logical that future increases in global temperatures will increase the intensity of these events (4th Assessment Report of the Intergovernmental Panel on Climate Change or IPCC 4AR [7]). Knutson [8] summarised the most important work on tropical cyclone simulations, including recent research that was done using higher resolution models than those used in the work that led to IPCC 4AR. This review suggests that the intensity of tropical cyclones could increase by between 2 and 11% by 2100, depending on the simulation used and the part of the world concerned. Authors such as Yasuda [9] conclude that indeed typhoons are likely to increase in intensity around the Japanese archipelago, and intensification of these events can cause a number of problems not only to Japanese coastal defences [10], but also to its society and economy coastal areas [11,12]. It is likely that these events in the future can knock down electricity distribution systems with increased frequency. All of these challenges make it imperative that the Japanese electricity supply system becomes more resilient and self-sufficient, so that local residents can have access to power even if transmission lines cut off or large power stations are brought offline.

In the aftermath of the 2011 *Great Eastern Japan Earthquake and Tsunami*, and to the compensate offline nuclear reactors, fossil fuel thermal power penetration increased significantly, with imports of Natural Gas (NG) and Heavy Fuel Oil (HFO) rising 36% and 121%, respectively [13]. Besides the economic and environmental impacts [14] of this rise in fossil fuel imports, it also increases the vulnerability of the already fragile energy supply sector. At the present, the Japanese government is revising its energy security strategy and reconsidering future dependence on nuclear power [15]. The expert panel on Future Energy Policy, under the Ministry of Economy, Trade and Industry (METI) is currently considering possible future directions for Japan's energy policy and reform of the energy supply structure, and should release an updated Basic Energy Plan (referred to as the *Innovative Strategy for Energy and the Environment*) in the near future [16].

A number of studies such as those by Refs. [14,17–19] have quantitatively examined energy generation mixes in Japan. However, these studies do not evaluate the reliability of the proposed energy scenarios. Furthermore, they simplify the analysis to yearly or monthly averages, disregarding daily and hourly supply/demand fluctuations (see Refs. [20,21]), which are particularly pertinent in cases when renewable energies have higher share in electricity grid mix [22]. The intensity of solar radiation wind patterns and population density all vary geographically, and statistical studies that do not account for this geographical variation using country-level data are potentially flawed). To the authors' knowledge, the only research that has attempted such a system is by Ref. [22] and in Ref. [23], however both studies were conducting before the Fukushima incident. In a post-Fukushima context, nuclear power share is uncertain and most likely it will be limited to the already constructed/under construction reactors.

It is generally believed, however, that renewable power poses a problem to traditional grid systems when its share is higher than 20% [24]. This is due to fluctuations in the electricity produced by these systems, which generally depends on the time of day and season. In particular, the production of wind and electricity from photovoltaics (PV) is highly dependent on weather conditions that are unstable and cannot be adequately predicted, a problem often referred to as intermittency. Traditional grids were not originally designed to cope with significant peaks and falls in the electricity supply [25] and therefore load levelling and the absorption of fluctuations are believed to represent a problem for the widespread use of renewable power. However, Ref. [22] showed that this problem of intermittency could hypothetically be attenuated in large countries such as Japan provided that an efficient long-distance grid distribution system was in place. Unfavourable