Potential for Wind Power Development at Yama-Kawa District, Japan

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Visby, 19 October 2020

PROJECT SUMMARY

This report has selected Yama-Kawa district in Japan as the object with potential for wind power development based on its unique geological and geographical background. Despite the challenges from various natural conditions (typhoons, volcanos, earthquake-related disasters and low-temperature), the favourable financial support system (currently FIT scheme and FIP scheme for the future) and the outstanding wind resources would make the profitability of the project almost guaranteed. Here four scenarios are given for evaluation, with the most IRR under 2020 FIT scheme plus ideal conditions being 33% and the least IRR under 2030 FIP plus lower bound conditions being 8%. Expectations have also been made about the possibility to design a pilot project with a spatiotemporal "thermal(biomass)-hydro-solar-wind" synergies system backed up by lithium-ion and volcanic-thermal based storage techniques on this site.

Key words

Onshore wind Japan, earthquakes, FIT scheme, FIP scheme, profitability.

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CHAPTER 1. INTRODUCTION

Japan is an island country located in east Asia and northwestern Pacific, with waters accounting for 85% of its total territory. The main part of land area, Japanese Archipelago, consists of four islands: Hokkaido, Honshu, Kyushu and Shikoku. Wide spread of mountainous terrain (about 73%) over the land and the archipelago itself is a typical product of plate movements, which in turn also result in volcanic activities and frequent earth tremors. Intense seismic motions may give rise to earthquakes that bring about other destructive secondary disasters. Fukushima Daiichi nuclear disaster, triggered by the 2011 Tōhoku earthquake and the consequent tsunami, for (an extreme) instance. However, situated on the Pacific Ring of Fire, volcanos, earthquakes and tsunamis are not the only things to withstand. Summer comes with typhoons in south developed from the low-pressure system on the ocean, and winter with heavy snows in north brought by the high-pressure system from the continent. These severe conditions have posed great challenges to its urban planning, also the siting of wind farms.

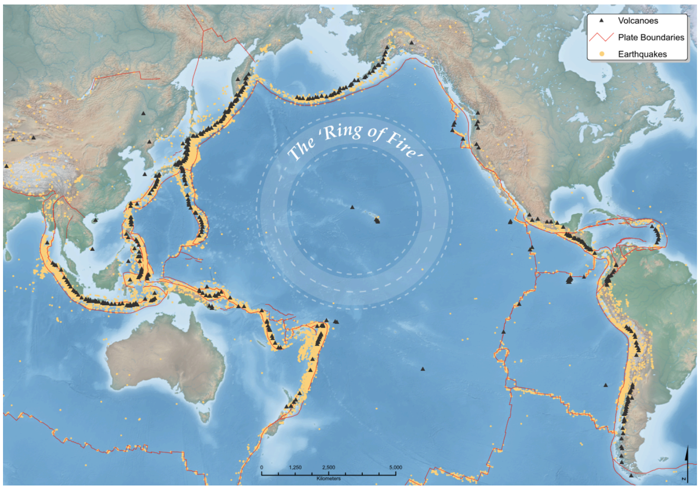

Figure 1: The ring of fire with volcanoes and earthquakes
(Source: Earth observatory of Singapore)

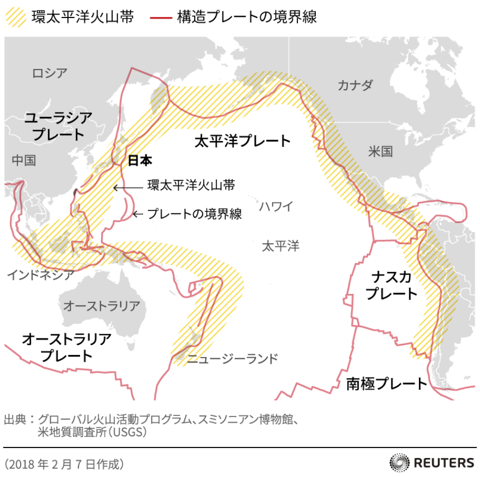

Figure 2: The ring of fire by regions
(Source: Reuters Japan)

As the world's second most populous island country (126.3 million) with extensive mountain surface and large forest coverage (68.5%), places left for residence are rather limited (4.8%). Settlements are clustered on coasts, plains and valleys, densely populated and urbanised to a high extent. Honshu in particular, as 81 percent of the whole population (104 million) has concentrated there, and the density reaches 2642/km^2 for the Great Tokyo Area[1].

Economics activities on a massive scale is a requisite for also a result of enabling such a lot of people to support their lives, while the massive activities are enabled by high energy capacities, for the most part fossil fuels under current structure (87.4% in 2017). Yet the poor storage of fossil fuels due to limited geological conditions resulted in the self-sufficiency of energy supply. The situation is even worse after the Fukushima disaster as nuclear plants are shut down and more fossil fuels are used for thermal power generation to make up the electricity deficiency. High dependency on fossil fuels especially crude oil (39% in 2017) imported (99.7% in 2018) from the Middle East countries (88% in 2018)[2] has exposed Japan to growing market uncertainty.

How to revive Fukushima from the long-lasting trauma, transform the energy system to secure the economy from natural, geopolitical or other unknown risks[3], and meet the climate target, have been the major concerns for the future development. According to the *Energy White Paper 2020* by the Ministry of Economy, Trade and Industry (METI), renewable energy, in terms of electrification and hydrogen society, plays a crucial role to address these problems altogether. The basic point for enhancement is to diversify sources, improve storage, widen and strengthen grid connection and digitalise control, supplemented with legislation and policy backup, such as the *Renewable Energy Special Measures Law* and the *Amendment Act 2020*. This includes amendment to the *Electricity Business Act* that emphasis the responsibility of the Organisation for Cross-regional Co-ordination of Transmission Operators Japan (OCCTO) in expanding and strengthening grid; and to the *Renewable Energy Act*, which manages to introduce the FIP scheme by 2022 based on the FIT scheme since 2012.

METI had also set up a 3E+S (*E*nergy security, *E*conomics efficiency and *E*nvironment + *S*afety) goal for 2030 in 2013, though the gap with regard to the current[4] energy mix is still significant. Specifically, they aim (the *Energy Mix 2015*) to increase the self-sufficiency rate to approximately 25% while the current rate is 9.6% (2017). In order to fulfil it, as for electricity generation, renewables are expected to make up 22 - 24% of the total (1.065 trillion kWh), which is 4 - 6% addition to the current level (2019). In respect of wind power, though granted favourable resources, with an estimation[5] of 144 GW onshore and 608 GW offshore potential capacity, Japan is still in the initial stage. The total installed capacity is 4279.1 MW for 455 farms[6], with wind energy contributing only 0.76% (2019) of the mix and the goal set by METI is only 1.7%, which is rather conservative compared with other developed countries. This is probably out of the consideration of adopting nuclear power as a more guaranteed option to fulfil the targets, energy security in particular. They suppose nuclear power to comprise 22 - 20% of the total while currently it takes up 3% (2017)[7]. Restarting nuclear plants is facing huge controversy[8] with waning public trust, thus how far it can go is actually in question.

In this context, despite the low government target for wind power, Japan is generally an ideal place to develop wind projects in terms of market potential, governmental support and public acceptance (by comparison). This report aims to investigate the feasibility and profitability of building an onshore wind farm at a specific site (Yama-Kawa district). In the following chapters we will first overview the geographical location of the site selected and analyse the challenges, mainly earthquake related, we might face. Then information regarding the site's wind resource will be provided. Next, we will go over the grid infrastructure, including other plower plants nearby, and discuss about the available and potentially available storage technology, i.e., battery system installed in the Nishi Sendai substation and the electrical thermal energy storage technology with volcanic rock. After that, we will introduce the necessary procedure to go through and permit to get in order for construction in a Class 1 Special Zone of a quasi-national park. Moreover, environmental and social-economical impact of building the wind farm will be assessed based on the information above. Finally the analysis of profitability will be conducted based on the current FIT scheme and the future FIP scheme. Conclusion remarks will be given to briefly summarise the report and evaluate the site.

CHAPTER 2. WIND POTENTIAL

2.1 Site Location

Yamagata-Kawasaki (or Yama-Kawa for short) is the borderline district between the city Yamagata in Yamagata Prefecture and the town Kawasaki in Miyagi Prefecture. The two prefectures lie right above the Fukushima Prefecture in the south half of Tōhoku Region, or Northeast Japan, on Honshu Island, as is shown in Figure 3. The closest city around besides Yamagata is Sendai, the capital city of Miyagi Prefecture and one of the 20 designated cities of Japan with a population of 1,091,407 in 525,828 households. Being the largest city of Tōhoku Region and the economy centre, Sendai is the most energy consuming area among the whole region, while Yamagata and Kawasaki has only about one-fifth and less than one percent of its population, thus it is easy to meet the local energy needs and the surplus power can be transmitted to more demanding places.

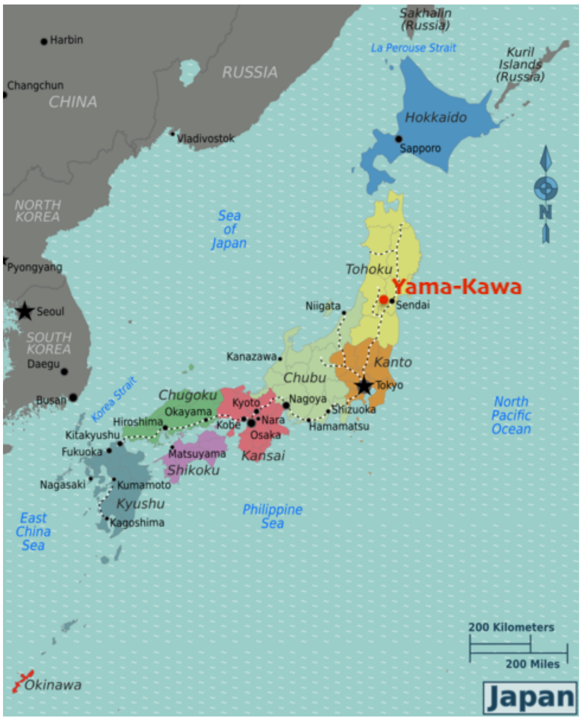

Figure 3: Japan regions map
(Original source: Wiki voyage 2009)

On the other hand, locating the site inland in mountains will keep it away from tsunamis and largely reduce the impact of typhoons. Since there is no record around this district for maximum wind speed and instantaneous wind speed over 40 m/s, which is lower than the survival speed of a normal turbine, there is no need to trade the blade length for a better stability. Conditioned the grid, which is more vulnerable to stormy weathers, can withstand the typhoon (usually the remnant of it), then what to concern about the impact on the farm itself mainly is the resilience of the site to water erosion caused by heavy rainfall. This is largely determined by the soil type, which we will come to later.

As we have mentioned that the site is located in mountains, Mount Zaō consist of an active cluster of stratovolcanoes. However, due to the distance from the crate, the main impact of steam or magma eruption if occurs would be ash fall (1cm as is shown in Figure 4), and it is also not in the area forecasted with the risk of debris flow afterwards. The one more noteworthy is the tremor brought by volcanic activities, which may lead to earthquakes.

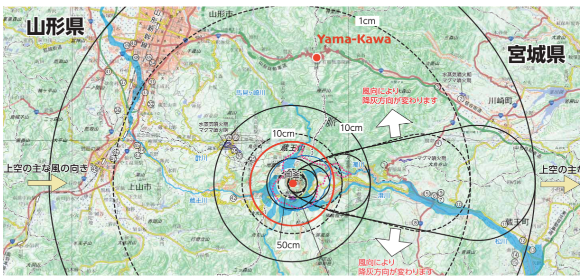

Figure 4: Volcano impact map
(Original source: Zaōzan hazard map 2017)

Even if there is probability of volcanic earthquakes, nevertheless, this district is among the places with relatively low probability of for severe earthquakes (6 lower on Japanese scale is chosen in Figure 5 as a representative intensity) in 30 years, compared with the cities on the “front side” of Japan that faces the Pacific.

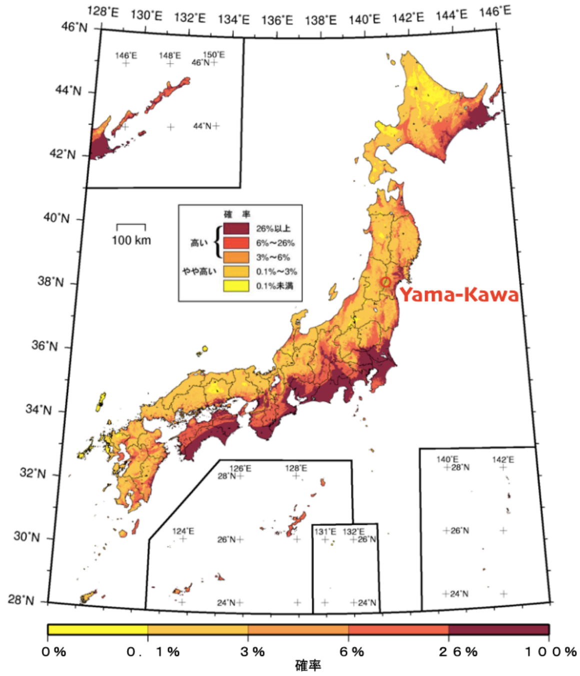

Figure 5: Probability of shaking with seismic intensity of 6 lower or higher in the next 30 years [Average case / all earthquakes]
(Original source: Probabilistic seismic motion prediction map 2019)

Despite the comparative advantage to other sites against earthquake, the probability is by no means zero, thus the possible impact of earthquake on the operation and the wind farm itself is to be carefully considered. Historically there are only two cases of wind farm damage related to earthquake[9] and the damage was somewhat limited. Yet as turbines are getting larger, how they may respond to it can have significant effect on their production. Aside from seismic motions and different loads caused by wind or earthquakes, the main aspect to consider is the soil structure interaction (SSI, i.e., the dynamic stiffness that specifies the force-displacement relationship, and the effective foundation input motion as a result of earthquake excitation). Additional aspects include liquefaction and scouring[10].

According to Vatanchian and Shooshtari (2018) in regard of our site soil conditions, the risk of farm damage due to earthquake itself can be effectively managed. Given the ground motion records of three real earthquakes with magnitudes (7.62, 6.93, 6.69) over the magnitude adopted above (6 lower equals to 5.5 - 5.9)[11], three turbine models with different base type in different states have been tested. Results show that for parked turbines, only the earthquake excitation involves in the input load, thus the damping effect of SSI, which decreases the interacting system response, is significant for the flexible-base model on soft soil conditions, as opposed to one on stiff soil conditions or the fixed-base model. For operational turbines, especially when the magnitude is higher, the flexible-base models undergoes significant whipping effect, which increases the response, while the damping effect is negligible. Particularly, if the soil has more stiffness, participation of earthquake loads in the total response will increase, thus matters more in the design of turbine, while if the soil is softer, the total response is to a large extent to the wind and will be less affected by the earthquake.

The soil distributed in this district is mainly aluandic and silandic andosols (or andisols)[12], a type of light, fluffy and aggregately stable volcanic ash soil as a result of ash fall accumulation. Its highly porous structure endows it with outstanding permeability, while the richness of allophane, imogolite and humus content at the same time grants it remarkable capacity of water retention. These unique properties enable it to rapidly drain the water even when the soil is saturated (Nanzyo 2002, 2006; Takahashi & Shoji 2002; Dahlgren R.A. et al. 2008). The low stiffness of this type of soil provides the site an advantageous anti-earthquake condition, since the damping effect of SSI will decrease the system response when an earthquake occurs, as long as the earthquake is timely monitored and a control system is available to switch the operational turbines to parked status. On the other hand, as for secondary disasters caused by earthquakes, i.e., liquefaction and scouring as mentioned, a proper evaluation is to be based on the specific hydrological data of the ground and surface water, but generally, they are as well about whether the sediment structure can withstand the erosion of fast-running water as what we concern about typhoons.

Here we take liquefaction for an example. According to School of Societal Science (2017), normally speaking, it is more likely to occur at places with poorly graded, loosely sedimented and saturated sandy soil, where the groundwater level is shallow and when an earthquake happens. But that is not the whole story. Considering the Tōhoku Earthquake, fine-grained sand that is supposed to be bearable also liquefied. Only 140 cases of housing damage have been found in Miyagi Prefecture, Tōhoku area, which suffered the biggest tremor, contrasted with 18674 cases in Chiba Prefecture, Kanto area. This is due to the fact that instead of mountains and hills, much larger total area of Kanto consists of lowlands and landfills that are vulnerable to liquefaction. Since our site is located in the mountainous and upstream district, with fine-grained and well-graded soils effectively conducting the water, the risk of liquefaction is supposed to be low. Yet considering its low bulk density owing to hydration, there is possibility for the soil to dry out during or after construction, with surface crumbling to hard granules that can be easily removed by run-off. Thus a thorough estimation ought to be conducted before any construction and if considerable risks exist, measures such as compaction or consolidation is to be implemented to prevent the damage, and the vegetation is better to be restored as soon as possible.

Besides the typhoon and earthquake related difficulties, another thing to concern is the icing problem. The temperature can be below 0°C during the winter especially for places at high elevations, and there are normally heavy snows around this area. A proper assessment for the impact again is to be based on the actual measurement so it is hard to go further here, but it would always be better for developers to take the possibility of deploying de-icing and anti-icing system for turbines into consideration.

Figure 6: Potential site location of the wind farm (marked by circle A)
(Original source: Google Earth 2020)

Figure 6 is a specific view of the location. As is mentioned this district is overall mountainous, with two national highways E48 (Yamagata Expressway) and 286 linking between Sendai and Yamagata. Location A is the site selected. Location B is a substation called Nishisendai (West Sendai) substation belonging to Tōhoku Electric Power (the major electricity supplier of Tōhoku region with headquarters situated in Sendai) Network. A 20 MW large battery system has been installed in the substation, and researches about the fluctuation caused by solar and wind power inflow on the grid frequency has been going on since 2015. The length of power lines connected the site and the substation as is shown by the yellow spots line in the figure is approximately 16 km. There is a smaller substation even closer to the site in Yamagata belonging to the same grid network, called Higashi Yamagata Substation, but currently no power line connects between them. Location C is a 53 MW solar power plant called Sendai Hi-land Mega Solar Project based on the former Sendai Hi-land Raceway. Other power plants nearby and possible grid connections will be further discussed in the next chapter for infrastructure.

The red area in Figure 7 shows a potential scenario of the coverage of site (i.e., the maximum range of site impact) with current surroundings. Besides the highways mentioned with the green and blue signs, there are two historical spots marked by cyan pins and a refuge hut marked by the pink pin. The spot closer to the site is a wooden board and physically will not affect the construction. The site is situated in the Zaō Quasi-National Park with the green pin in the figure. The green line delineates a pedestrian from the parking lot, by the power tower, across one of the historical spots and to the park.

Figure 7: Potential coverage of the wind farm
(Original source: Google Earth 2020)

The objective of siting the wind farm is to utilise the wind resources as possible conditioned on the available terrain, try to get close to roads and grids yet keep away from places of public interests (historical spots, pedestrians and views of the national park) as possible; meanwhile, make sure enough space has been left among turbines. Since no resident has settled here, the impact of noice can be minimised for the local community. Therefore, how to manage the visual impact of the wind farm on the landscape for the tourists will be the problem to concern. More detailed discussion about the impact will be provided in Chapter 3.

2.2 Wind Resources

As Figure 8 shows, if we single out the onshore wind resources of East Japan in terms of mean wind speed at 100 m, it is easy to find that the distribution of the most windy places (with wind speed > 9.75 m/s) is almost overlapping with the distribution of volcanoes. Despite the challenging accessibility, as is mentioned by Mizuno (2014), places with higher wind speeds are often in mountainous conservation areas, especially on ridges, which are previously[13] under strict protection but naturally beneficial from better wind resources. With regard to our site, for one thing, it is located around 38°N within the westerlies, thus experiences the prevailing wind especially during the winter. For another, strong wind, especially during the daytime, is generated from the central valley between Zaō Mountains and Hida

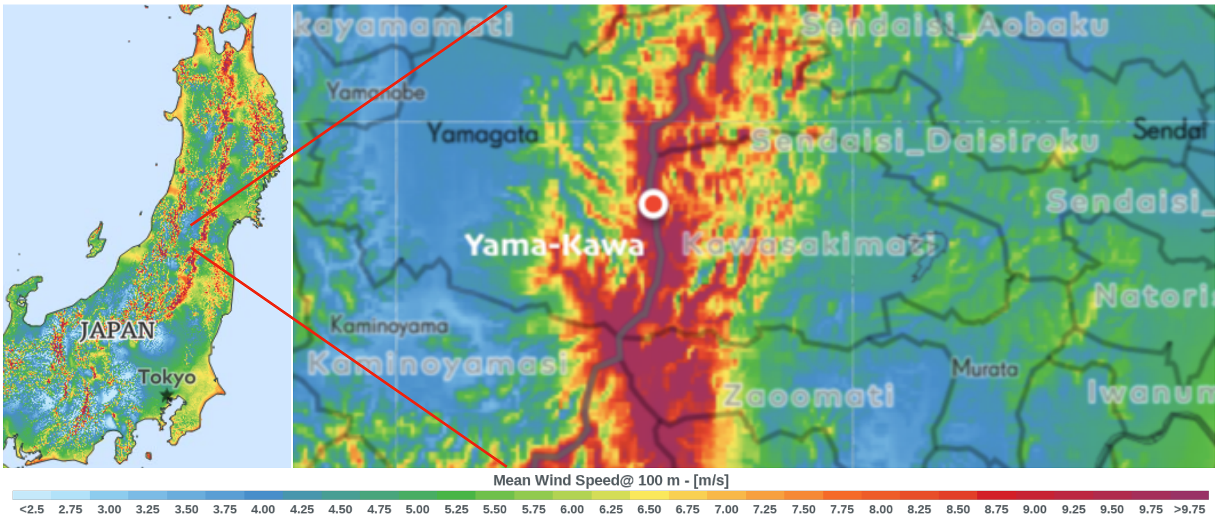

Figure 8: Mean wind speed map of East Japan and the selected site
(Original source: Global wind atlas 2020)

Mountains (or Northern Alps, another group of volcanoes parallel to Zaō), where Yamagata Prefecture lies in. Thus for the site situated on a level ground of the ridge of Zaō, the wind is predominantly from west as is shown in Figure 9. According to the measurement of Global Wind Atlas, this district has a mean wind speed of 12.56 m/s at 100 m hub height with a mean power density of 2530 W/m² for the 10% windiest area, and a mean wind speed of 12.58 m/s at 50 m hub height with a mean power density of 2794 W/m² for the 10% windiest area. This wind resource is to be graded as Ia - Ib High depending on the turbulence level based on an IEC classification.

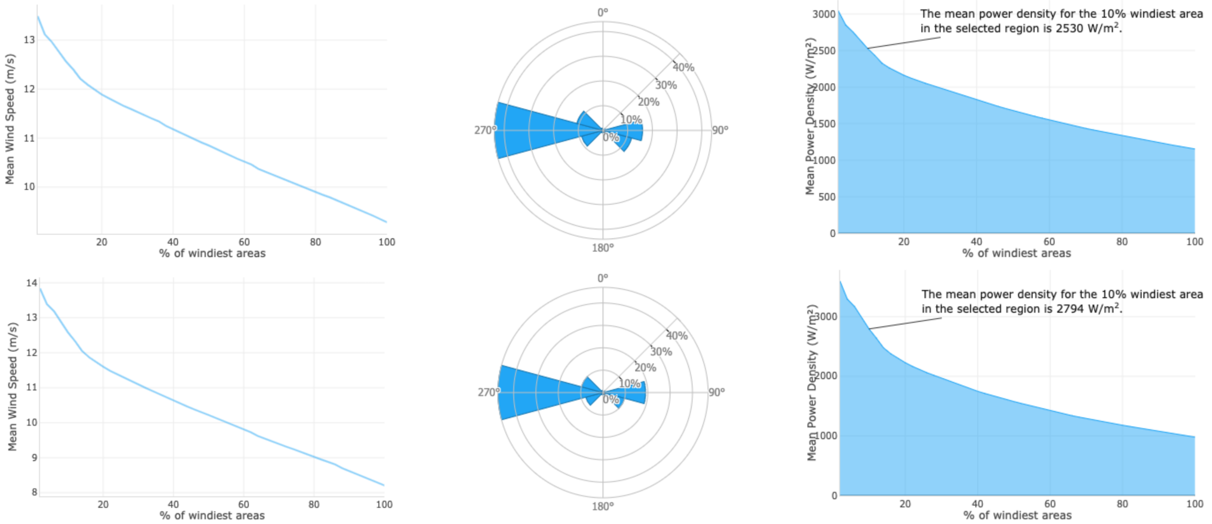

Figure 9: Wind resources of the selected site
(Original source: Global wind atlas 2020)

Since the wind comes from the valley, the mean wind speed and mean power density for a lower hub height is greater than a higher one, thus it is also a site suitable for installing small turbines, and small turbines are much easier for transport regarding the winding mountain road. Yet as is discussed above, we have to be very restrictive about the location of turbine installation, thus have less flexibility on the wind variation. Hence a higher hub would be favourable for a more expectable output.

CHAPTER 3. GRID INFRASTRUCTURE

Japan used to have a rather inflexible grid system as the East Japan is using a 50 Hz frequency system and the West Japan is using a 60 Hz one, while both the frequency conversion capacity and nationwide electricity transmission capacity were very limited, plus a non-liberalised electricity market. The ten regional monopoly Electricity Power Companies (EPCOs), Tōhoku Electricity Power included, have great political and economical power so that the progress of electricity sector reform was quite slow. However, the Great Earthquake broke this power structure and new players, OCCTO and the Electric Power Development Company (J-Power) entered into the transmission and distribution network. The retail sales and power generation markets have been fully liberalised since 1 April 2016 and from the very same day 2020, utility companies running transmission and distribution business are required to unbundle their generation and retail business in accordance with the amended *Electricity Business Act*. Under the same act, operators of transmission and distribution must not refuse any request for grid connection, unless there is risk of electric or magnetic faults on the function or other justifiable reasons. The application can as well be directly submitted to OCCTO for further coordination

In return, the power producer will have to meet certain rules posed by the utility companies such as output curtailment, otherwise they have the right not to enter into the FIT purchase agreement. In regard of our site, curtailment might be a problem considering the current distribution of transmission line. As can be seen in Figure 10, the high voltage (500 kV) transmission line is considerably sparse in Tōhoku region compared with regions such as Kanto, Chubu or Kansei. Meanwhile, as is pointed out by Wakiyama & Kuriyama (2018), wind power including certified capacity in Tōhoku region is far beyond the amount of generated power that is connectable to the grid[14]. If there is energy surplus and the surplus cannot be transmitted to more demanding areas or areas with deficient supply, it may end up being curtailed. However, according to their simulation of demand and supply curve in Tōhoku Region for a 2030 scenario with the energy mix target being achieved[15], the curtailment risk of our site seems to be low. Since the solar power generation is not enough large while demand for electricity is relatively high in the winter (February), the energy supply does not exceed the regional demand, and vice versa for spring (April) or summer time. As we have discussed in the last section, the our site experiences particularly strong prevailing wind during the winter, plus contribution of the site elevation, the wind speed reaches its peak in February, and vice versa for spring or summer time[16]. The production curve of our site almost fits the regional demand curve thus the output is less likely to be curtailed, and it can compensate the solar power for its seasonal variation. Even if there

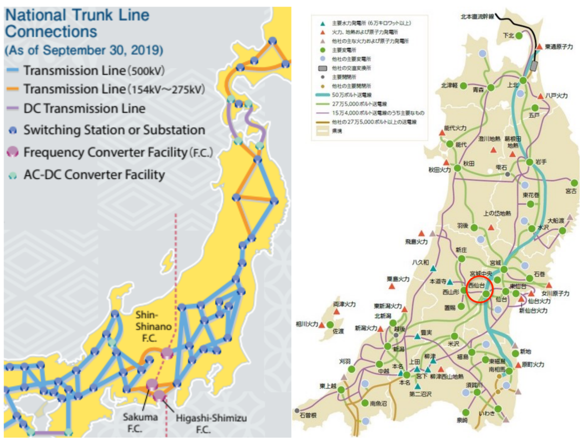

Figure 10: Main part of the gird on Honshu island & Grid network of Tōhoku Electricity Power (Original Source: Electricity review Japan 2019 & Tōhoku Electricity Power NOW CSR report 2018)

is surplus, as we have mentioned in the section of site location, there is a 20 MW battery system in the nearby substation that can be used for energy storage.

Here we back to the grid infrastructure of our site. Tōhoku Electricity Power has a power transmission network with a line extension of about 25,000 km throughout the Tōhoku and Niigata regions. Their equipments are strengthened against severe natural conditions as strong wind or earthquakes to prevent grid damages. As is mentioned above in Figure 6, the length of the transmission line from the site to Nishi Sendai substation (marked by the red circle on the left side of Figure 10) is about 16 km, and the substation has 154 kV (the thin purple line) and 275 kV (the middle green line) transmission line for the horizontal connection and 500 kV (the thick blue line) for the vertical. In other words, if the wind farm have access to this substation, the power it generates can reach almost everywhere, and the balance can be better managed by utilising the battery system installed. The research conducted there from 2015 to 2018[17] shows that the system has an enlarging effect of 120 - 470 MW on the frequency fluctuation adjustment for wind power inflow, thus can largely mitigate the impact of wind variability.

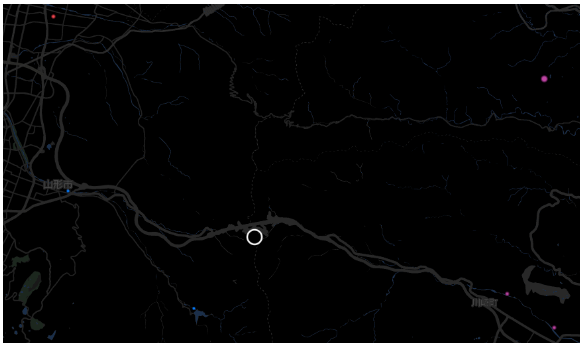

Figure 11: Power plants around the selected site (Original source: Electrical Japan 2020)

On the other hand, besides the 53 MW solar plant (the pink spot on the upper right corner), there are several other plants around this area as can be seen in Figure 11. The white circle denotes our selected site. The red spot on the upper left corner is a 3 MW biomass thermal plant. The blue spot right below the red is a 0.14 MW hydro plant. The other lower blue point by a lake is a 0.48 MW hydro plant. The two pink spots on the lower right corner are solar plants of 1 MW and 2 MW respectively. As is discussed above, the wind and solar resources around this area chronically mesh with each other quite well, while they are distributed mainly on the Kawasaki, Miyagi side, and currently there is only a 154 kV transmission line horizontally between the Nishi Yamagata (West Yamagata) substation and Nishi Sendai substation. However, since the thermal and hydro plants on the Yamagata side can offer stable support for seasonal variations of solar and wind, if better grid connections can be expanded among these two prefectures, especially from Sendai and Kawasaki to Yamagata, the spatiotemporal "thermal(biomass)-hydro-solar-wind" synergies[18] plus the backup from battery system will be able to provide flexible and reliable electricity supply for this area.

For an even further future scenario, as we have seen in Figure 8, wind resources along the ridges of the volcano groups are overall outstanding. If they can be developed properly, the wind power capacity of this area would be huge, and there would be a considerable amount of energy excess. This excess if properly stored, would make big differences especially when some natural disasters occur. To store this much energy, the traditional lithium-ion batteries can be expensive and insufficient to meet the needs. The electrical thermal energy storage (ETES) system that uses volcanic rock as the storage medium would be an ideal alternative with respect to this area. The electricity driven heater and blower heat the rocks to store the energy, and the heat is output or converted back to electricity through the steam turbine. Since places with the best wind are basically the source places of volcanic rocks, this can form a sustainable system for energy production and storage. According to the planner of this pilot project, Siemens Gamesa Renewable Energy[19], the commercial rollout is supposed to be done in the mid 2020s, thus there is likelihood for it to be applied in the wind farm on this site.

CHAPTER 4. PLANNING AND PERMISSION PROCESS

According to the 2020 Revision of the Electricity Business Act, to run a business in electricity as a power generator, there is no legal requirement other than providing a filing to notify METI, and other regulations will also be minimal. To construct electricity generation plants, if the generation capacities exceed certain thresholds, wind farm with capacities over 10,000 kW for instance, construction plans must be submitted to METI in advance. Also, for construction of Type I power plants given the same thresholds, environmental impact assessments (EIAs) is to be done in advance and every year after. Yet it is a procedure approach instead of a regulation, the purpose is to make the developing decision more environment friendly and form social (residents, municipality and public administration) consensus. The procedure basically can be divided into 5 steps. First is to file the “primary environmental impact consideration” with comparison of multiple plans. For a wind power project, the aspects to consider are noise, vibration, ground, soil, animals and plants, ecosystem, landscape and places of interaction with nature. This also requires opinions from citizens, prefecture governor, municipal mayor and the environmental minister. Second is for the above opinion holders to scope the document so that the assessment method can be determined. Third is to implement the survey, forecast or evaluation so that a primary version of “environmental impact statement” can be drafted. Based on the public and local administrative opinions, fourthly, a formal EIS should be submitted to the environmental minister for feedback to form the final version. The final step is to construct the project, take related measures and follow-up survey, such that the assessment result can be reflected. Therefore, an “impact mitigation report” with opinions from the environmental minister should be announced to the pubic.

The actual regulation involved in the planning process of this site is *Natural Parks Act*, as permissions are required for construction in Special Zones of natural parks. Yama-Kawa district is included in the Class 1 Special Zone of Zaō quasi-national park mainly because it is situated on the peak line of Zaō Mountains. Though there are quite a few established power towers and power lines, and the vegetation mainly consists of grass and low bushes, for the sake of landscape continuity it is still under the restriction. The act is last amended in 2014 and according to Kato et al. (2015), some projects are permitted by applying exception of the act and deleting the landscape’s permission standard. Projects at an ordinary zone can also be canceled due to the site having a natural resource at Special Zone level. In other words, whether a project is actually granted a permit is determined by how much the project may impact the surroundings and how much it is of public interest. These will be topics of the next chapter and the procedure is to be went over first. The permission investigation can be integrated with the EIA process. The first stage is site selection and decision, the content of which is also to be included in the first step filing of EIA. This stage is to exclude the environmentally unavailable places. The second is to file a general plan that confirms whether and how much the major viewpoints might be affected by the wind farm given various visual properties (ranges, directions, skylines, control lines, structures, colours and so on). The third is to file a specific plan that explains how the view can be conserved and conducts forecasts for the measures considered, such that their validity can be assured. These two stages are to be included in the third step of EIA, and after a consensus is formed based on opinions from various stakeholders, the plan can be confirmed and submitted for permission acquiring.

As for public reception, it can be exemplified by a survey[20] conducted in Akita prefecture in 2019, since Akita prefecture is also[21] a model area selected by Ministry of the Environment (MOE) to examine the zoning methodology for the installation of wind farm. According to the survey, the thing that people worry most is decommission of turbines, followed by accidents and noise, while they also expect that wind power can contribute to de-carbonisation and energy self-sufficiency both regionally and nationally. Therefore, to be enough restrictive and cautious for the project, considerate for benefits of the community, and open for public knowledge and participation, would be the key aspects to gain social credence also the permission. This requires in-depth and comprehensive conversation with both direct and various potential stakeholders to make sure their concerns and needs.

CHAPTER 5. ENVIRONMENTAL AND SOCIAL-ECONOMIC IMPACTS

5.1 Environmental Impacts

The main concerns of the site impacts selected here are noise, soil, birds and the landscape, as several facilities are already established and all the other impacts due to construction would be marginal. First, since the site is one of the places to entry the park and no residential settlements nearby, the noise can only affect the tourists. However, it also means that the tourists normally will not stay here for a long time, thus the impact will actually be limited. Second, as we have mentioned in the site location part, there is possibility for the soil to degrade due to construction, thus also for the sake of safe operation against natural disasters, it is important to make sure the vegetation, currently grass and low bushes, is timely recovered. Third, this district is situated within a prefectural wildlife refuge, yet the protection of bird is mainly aiming at hunting restriction and prevention, thus no regulatory limit on construction. It is also not a place of large scale habitat, migratory or breeding ground for ordinary or rare birds, so physically the likelihood of birds killing would be relatively low. But still it is better to equip some monitor device just in case the blades clash with bird flocks passing by, as it is still close to the natural realm of the park. Fourth, how to design the wind farm so that it can be properly integrated to the landscape without being prominent or blocking the sight too much from any view points would be a serious problem. The ideal scenario is to form a new landscape via an aesthetic arrangement of natural and artificial things and to leave the tourists a positive visual impression instead. This can be rather challenging but wind farm is the most likely option to this purpose compared to other kinds of plants.

5.2 Social-Economic Impacts

The most straightforward impact to the public interest of siting a wind farm here is that the refuge hut can be powered sustainably. A successful example[22] can be found in France, the Refuge du Goûter. This refuge hut is powered by renewable energies and has a fully autonomous integrated system. Such kind of project is not only beneficial for tourists, but also of educational significance, as local schools organise visits to show kids the eco-friendly and low-carbon design concept. Developers may consider offering help to renovate the refuge hut as a means to enhance connections with the local community.

For a wider and further impact, with regard to Sendai, the coastal area of which suffered a lot from earthquakes and tsunamis, a wind farm sited here will provide a reliable backup for its energy supply. Since it is the logistic and transportation centre of Tōhoku Region, with clusters of high-tech ventures from Tōhoku University and information related companies, sufficient and better cheap electricity is a necessity for the process and analysis of data on a large scale. Better facilities will also attract more enterprises to settle here, thus the wind farm would be conducive to the local and regional economic growth especially after the Great Earthquake. With regard to Tōhoku Region or the whole East Japan, since there will be considerable depopulation for places outside the Great Tokyo Area in the coming years, this kind of project would help to reallocate resources and population among regions, balance interregional demand and supply (as is shown in Figure 12), and enhance the overall resilience of the nation against natural disasters and other risks.

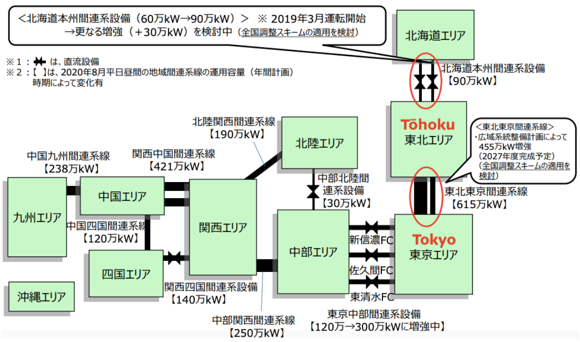

Figure 12: Status quo and future plan of interregional grid connections (Original source: METI 2020 b)

CHAPTER 6. FINANCIAL SUPPORT SYSTEMS AND PROFITABILITY

In Japan, the FIT scheme has been implemented for renewable energies since 2012. The mechanism basically is that, an electric utility is obligated to accept the request from a renewable energy producer under the *FIT Act*, to purchase electricity for a long term period at a fixed price guaranteed by the government, normally above the market price to a certain extent and uniform among the country. This scheme has been proved to be rather successful to promote the installation of renewable energies as the capacities have been tripled in 7 years with the world's top class growth speed. However, the success mostly goes to solar PV as it has much less regulatory limits, while the low cost advantage of wind power was unable to present as the scheme itself prevents customers and investors from receiving right signals from the market. Things change as the Feed-in Premium (FIP) scheme will be introduced by 2022 under the *Renewable Energy Special Measures Law*. A fixed premium will be added on the price of electric market so that the resulted price can still partially reflect the actual relation of demand and supply. This will give play to the advantage of wind power and promote the economies of scales.

To estimate the profitability of wind farm we have to first calculate the expected revenue. Currently (2020) the price for onshore wind under the FIT scheme is 18 JPY (about 0.15 EUR) plus tax per kWh for a period of 20 years. For our site we select the GE 5.3-158 MW onshore wind turbine launched in 2018 with regard to the characteristics discussed in section of site location. Firstly, the turbine has a revolutionary design for a two-piece jointed blade which can be assembled on site to fit all sorts of terrain, thus largely reduces the limit of transportation due to twisting mountain roads. Secondly, the turbine has an advanced control system for load management such that risks brought by earthquakes or other natural disasters can be effectively mitigated. Thirdly, the rated speed matches the mean wind speed of our site hence the rich wind resources can be sufficiently made use of. Since the places available for turbine installation are limited, we expect to install 3 - 5 turbines with 101 m hub height on this site, thus the planned capacity will be 15.9 - 26.5 MW. For the sake of landscape conservation, here we consider the situation with the least turbines (3), thus the capacity will be 15.9 MW. According to the power curve given by thewindpower.net based on the actual data from wind farms in Australia, Brazil and Sweden, the annual energy production (AER) can be calculated with a Rayleigh distribution of yearly hours (for details see Appendix). Conditioned a mean wind speed of 12.56 m/s at 100 m, the expected AER is 30,373,355.56 kWh, or 30,373 MWh per turbine, with a capacity factor of 65.4%.

Second is the costs side. The capital costs (CAPEX) and the operation & maintenance costs (OPEX) estimated for onshore wind power installation in 2020 given by MOE (2019) is 282,000 JPY/kW and 9,300 JPY/kW/yr respectively. Following the assumptions adopted in the report from Carbon Tracker, Institute for Future Initiatives The University of Tokyo, and CDP Worldwide-Japan (2019), the return on equity is set to be the mid value 14.67%[23], the cost of debt on short and medium term is 0.99%, and long term for 1.99%[24]. The debt/equity ratio is assumed to be 80% / 20% with the corporate tax rate being 29.74% according to IEA Wind TCP Task 26 (2018). With the information we can calculate the payback period, the weighted average capital cost (WACC) as the discount rate of the net present value (NPV), and the internal rate of return (IRR). Since the FIT price is guaranteed for a period of 20 years, here we assume the project to last for 20 years. The results (per turbine) are listed in the table below.

<table>
<tr><td>Mean wind speed</td><td>Turbine capacity</td><td>AEP per turbine</td><td>FIT 2020 electricity price</td><td>Annual revenue plus tax per turbine (AEP * P_{FIT})</td><td>FIT period</td></tr>
<tr><td>12.56 m/s</td><td>5300 kW
(5.3 MW)</td><td>30,373,355.56 kWh
(30,373 MWh)</td><td>18 ¥/kWh + tax
(0.15 €/kWh + tax)</td><td>546,720,400.08 ¥ + tax
(4,537,779.32 € + tax)</td><td>20 years</td></tr>
<tr><td>Debt / equity</td><td>Return on equity</td><td>Cost of debt</td><td>CAPEX
per turbine (*5300)</td><td>Annual cost (OPEX)
per turbine (*5300)</td><td>Tax rate</td></tr>
<tr><td>80% / 20%</td><td>14.67%</td><td>short / medium: 0.99%
long: 1.99%</td><td>1,494,600,000 ¥
(12,405,180 €)</td><td>49,290,000 ¥
409,107 €</td><td>29.74%</td></tr>
<tr><td colspan="2">WACC after tax shield</td><td>Annual net cash flow
(revenue - cost)</td><td>Payback Period</td><td>NPV per turbine
with WACC as discount rate</td><td>IRR</td></tr>
<tr><td colspan="2">short / medium: 3.49%
long: 4.05%</td><td>497,430,400.08 ¥
4,026,168.27 €</td><td>3.0 years</td><td>short / medium: 5,581,482,672 ¥
long: 5,235,809,134 ¥</td><td>33%</td></tr>
</table>

Table 1: Profitability of each turbine under FIT scheme 2020 with ideal conditions

From the results we can find that the IRR under the theoretical wind conditions is particularly high. This may due to several reasons. First, the wind speed of the site is overestimated. The only source of the latest wind resources in Japan is Global Wind Atlas. It is possible that the measurement method adopted exaggerated the actual situation, or the data collected is not comprehensive or precise enough. Second, the power curve of this turbine can also be inaccurate since it is new and the data available is limited. Meanwhile, aerodynamics or mechanics-related losses have not been included in calculation. Though the high AEP can also be the result of technology advance as is highlighted by GE, it is to be prepared that the actual yield might be lower than expectation to some extent. Third, the cost of debt in Japan has been remarkably low[25] as the risks mostly are borne by the public sectors[26]. This may further result in an even higher leverage than 80% / 20%. By contrast, the interest rate or interest margin in other OECD countries can be a few times higher. Fourth, the electricity price under the FIT scheme is also significant high (almost tripled) compared with other OECD countries and the income under such pricing will be considerable. On the other hand, the CAPEX and OPEX estimated by other studies are actually lower than those we adopted in calculation provided by the government. This setting is better to be kept considering the potential costs caused by natural disasters discussed above. So far, only the first two points might lead to an overestimation in our calculation, with others factually contributing to a high IRR. Therefore we can consider a lower bound scenario for the AEP to be reduced by 15% and redo the calculation. The simplified results are listed in the table below.

AEP per turbine	Annual revenue plus tax per turbine (AEP * P_{FIT})	Annual cost (OPEX) per turbine	Annual net cash flow	Payback period
25,817,352.23 kWh (25,817 MWh)	464,712,340.07 ¥ + tax (3,857,112.42 € + tax)	49,290,000 ¥ (409,107 €)	415,422,340.07 ¥ (3,448,005.42 €)	3.6 years
NPV per turbine	Annual net cash flow for the farm (*3)	NPV for the farm (*3)	Variance to scenario 1	IRR
short / medium: 4,414,895,723 ¥ long: 4,126,211,095 ¥	1,246,267,020.20 ¥ (10,344,016.27 €)	13,244,687,169 ¥ 12,378,633,285 ¥	-21%	28%

Table 2: Profitability of the project under FIT scheme 2020 with lower bound conditions

From the results we can find that, even when the AEP is reduced by 15%, the IRR is still high enough to maintain a rather good profitability. In other words, given the high electricity price and the low debt interest rate, under the current scheme, the profitability of the farm is almost guaranteed. However, if we are planning for a project later than 2022, the new FIP scheme may change this scenario to a great extent. In the wholesale market, according to Japan Electric Power Exchange (JEPX), the current price is around 5 JPY/kW, which is 1/3 of the FIT pricing. Though how much the premium will be is yet to be known, the target price for wind power by 2030 is 8 - 9 JPY/kW, which is about 1/2 of the price for onshore wind, 1/4 of the price for offshore wind and 1/6 to 1/7 of the price for small scale (less than 20 kW) onshore wind at 2020 level. On the other hand, the FIT price has been experiencing a 1 JPY/kW decrease every year since 2018. Considering the target is to decrease the price for about 10 JPY in 10 years, it is reasonable to use year to estimate the future average price. Here we can speculate a 2025 scenario (13 JPY/kW) and a 2030 scenario (8 JPY/kW) based on the lower bound conditions.

FIP 2025 electricity price	Annual revenue plus tax per turbine (AEP * P_{FIP})	Annual cost (OPEX) per turbine	Annual net cash flow	Payback period
13 ¥/kWh + tax (0.11 €/kWh + tax)	335,625,578.99 ¥ + tax (2,785,692.31 € + tax)	49,290,000 ¥ (409,107 €)	286,335,578.99 ¥ (2,376,585.31 €)	5.2 years
NPV per turbine	Annual net cash flow for the farm (*3)	NPV for the farm (*3)	Variance to scenario 2	IRR
short / medium: 2,578,885,959 ¥ long: 2,379,892,198 ¥	859,006,736.97 ¥ (7,129,755.92 €)	7,736,657,877 ¥ 7,139,676,594 ¥	-42%	19%

Table 3: Profitability of the project under FIP scheme 2025 with lower bound conditions

FIP 2030 electricity price	Annual revenue plus tax per turbine (AEP * P_{FIP})	Annual cost (OPEX) per turbine	Annual net cash flow	Payback period
8 ¥/kWh + tax (0.07 €/kWh + tax)	206,538,817.84 ¥ + tax (1,714,272.19 € + tax)	49,290,000 ¥ (409,107 €)	157,248,817.84 ¥ (1,305,165.19 €)	9.5 years
NPV per turbine	Annual net cash flow for the farm (*3)	NPV for the farm (*3)	Variance to scenario 2	IRR
short / medium: 742,307,183 ¥ long: 633,032,086 ¥	471,746,453.52 ¥ (3,915,495.56 €)	2,226,921,549 ¥ 1,899,096,258 ¥	-84%	8%

Table 4: Profitability of the project under FIP scheme 2030 with lower bound conditions

From the results we can find that, the profitability is very sensitive to price, but even when the price fall to the 2030 level, the project can still make profits. A 8% IRR is also the level suggested by MOE for reference of the financial agencies to evaluate wind power projects[27].

CHAPTER 7. CONCLUSIONS

This report has given a rough analysis about the feasibility and profitability of siting a 3 turbines wind farm at Yama-Kawa District. Despite multiple challenges from natural conditions (typhoons, volcanos, earthquake-related disasters and low temperature, commonly faced by almost the whole country) and permission procedures, the potential for wind power development is huge with respect to outstanding wind resources and generous supporting systems. Though more in-depth studies based on precise and thorough data are to be conducted in order for its realisation. If realised, the impact it can bring to the region even the nation will much outweigh the costs. The ideal scenario is to turn it into a pilot project for a model of a spatiotemporal “thermal(biomass)-hydro-solar-wind” synergies system backed up by lithium-ion and volcanic-thermal based storage techniques, hopefully furthermore a model of a widely engaged, social and eco-friendly wind project. As electricity prices will be more and more determined by market through the introduction of FIP scheme, the profitability of wind power projects will tend to rely on economies of scale instead of high prices. Yet the geographical peculiarity of Japan might limit the scalability of the projects. Therefore, how to better fit the environmental and social conditions for a particular place, while hinder the eco-system as little as possible, and figure out the space that enables nature and human being to thrive together will be the concerns for the future development.

NOTES

[1] The actual data can vary as this page (Wikipedia 2020) also cited from different sources in different years.

[2] The latest data available is also from different years, see METI (2019) for details.

[3] Unpredicted global incidences, Covid-19 Pandemic for instance.

[4] All the “current” amounts or levels refer to the amounts or levels of the latest available data.

[5] The estimation is conducted by Japan Wind Power Association, see JWPA (2014) for details.

[6] See Electricity Japan (2020 b).

[7] See METI (2019) and ISEP (2020).

[8] Many surveys have been conducted after the nuclear disaster concerning about the public opinions to nuclear about in multiple dimension. The number of most relevant results can be found on google scholar after 2011 is over 5000 and still growing.

[9] See Swiss Re (2017).

[10] These aspects are also indicated by Swiss Re (2017) and the information for liquefaction and scouring can be found on USGS websites: https://www.usgs.gov/news/earthword-liquefaction for liquefaction and https://www.usgs.gov/news/earthword-scour for scouring.

[11] The power of the turbine being tested is 5MW, also close to the turbine being selected (5.3MW) for this site, which will be further discussed in the following sections.

[12] From https://soil-inventory.dc.affrc.go.jp/kokusai.html. The types of the soil surrounded are Cambisols, Podzols, Leptosols with rocks, as normal products of a mountainous terrain.

[13] The amendment of the Technical Guidelines for Wind Energy Installation in the Natural Park Areas in 2013 has settled the siting problems for the most part according to the same reference.

[14] See the “Wind Power Capacity” part of Figure 4 in the paper.

[15] See Figure 8 in the paper.

[16] See Appendix B for the month and hour (UTC) wind speed index.

[17] See Tohoku EPCO (2017).

[18] See Sterl et al (2020) for a “hydro-solar-wind“ model.

[19] For more information of the Future Energy Solution project and the ETES Strategy see their website https://www.siemensgamesa.com/products-and-services/hybrid-and-storage/thermal-energy-storage-with-etes; and also https://www.powermag.com/volcanic-rock-offers-new-take-on-energy-storage/.

[20] See Sakigake Japan (2019).

[21] See MOE (2019 b). Yama-Kawa district also lies in the range of the model area in Miyagi prefecture.

[22] For details of the project see https://www.buildup.eu/en/practices/cases/refuge-du-gouter-highly-energy-efficient-autonomous-mountain-hut.

[23] Originally sourced from NYU Stern, A. Damodaran (2019). Available: http://people.stern.nyu.edu/adamodar/New_Home_Page/datacurrent.html

[24] Originally sourced from World Bank (2019). Available: https://data.worldbank.org/indicator/FR.INR.LEND?locations=JP.

[25] For the specific marginal rates offered see https://www.reuters.com/article/japanese-wind-fans-bank-interest-idUSL4N2B637H.

[26] See Baker & McKenzie (2015).

[27] See METI (2020 d) for the FIT prices of recent years for onshore wind, and MOE (2019 c) for the suggested IRR value.

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APPENDIX A

Wind Resource Calculation

Variable	Value	Unit
Mean velocity	12.56	m/s
Nominal power	5300	kW
Scale factor	14.17	m/s
Maximum energy yie	46428000	kWh
Capacity factor	0.654	-

U	h distribution of yearl	Power curve	Energy yield
0	0.00	0	0.00
1	86.79	0	0.00
2	171.01	0	0.00
3	250.21	88	22018.56
4	322.19	310	99878.33
5	385.09	657	253002.72
6	437.48	1168	510975.14
7	478.40	1876	897486.68
8	507.40	2761	1400943.44
9	524.50	3668	1923883.29
10	530.18	4452	2360371.34
11	525.31	4998	2625475.76
12	511.06	5253	2684585.45
13	488.85	5300	2590913.57
14	460.24	5300	2439261.36
15	426.82	5300	2262131.76
16	390.16	5300	2067847.78
17	351.74	5300	1864210.98
18	312.87	5300	1658218.71
19	274.69	5300	1455866.93
20	238.12	5300	1262038.08
21	203.86	5300	1080467.61
22	172.41	5300	913778.09
23	144.07	0	0.00
24	118.97	0	0.00
25	97.10	0	0.00
26	78.34	0	0.00
27	62.48	0	0.00
28	49.28	0	0.00
29	38.43	0	0.00
30	29.63	0	0.00
		Total	30373355.56

APPENDIX B

Month and hour (UTC) wind speed index