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The Eastern Japan Earthquake and Tsunami: its Effects, Aftermath, Lessons learned

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Abstract
it's clear to the world that the eastern Japan earthquake was the biggest disaster the modern world had ever came to face, that's why it was of great importance that we took crucial lessons of it on every aspect possible so that we can be more ready for future disasters, no matter what is their scale, because as we know disaster are going to come, in all shapes and kinds, and a major disaster like the Great Eastern Japan Earthquake is going to be upon us every few decades, so being ready, as calculations have proofed, spending and providing for the preparedness phase, is 7 times better, safer and cheaper, than trying to solve the problems in the recovery phase, after the disaster happens, in this study we'll be doing an analysis of the event, and suggesting numerous solutions to prevent the likelihood of a similar scenario in the future.

1. Introduction

This earthquake caused a disturbance to the whole extension of the Pacific Ocean, which lasted more than 12 hours, but the main wave hit the shores of east Japan causing many casualties. After about 1 hour the tsunami waves hit the Japanese shore, they were thirty-nine meters high and travelling at about 690 km/h in the open sea and then slowing down to about 50km/h when they reached shallow water, then eventually hit the city.(Norio et al., 2011)
The tsunami hit many cities, but the biggest number of casualties was in Fukushima.
The focus here will be at the approaches taken by the Japanese government and what are the positivity's and the negativities of those implementations and how well they are going so far.
The main objective of this study is to compare the case of the Daiichi Nuclear Powerplant unfortunate event to other case studies that went through similar circumstances yet being able to overcome it with minimal damage.

1.1. Methodology

The used methodology will include going through the literature reviews on concepts such as disaster response, preparedness for various kinds of disasters, and the application of both in a wide scale globally, the research framework and base material were built on this information.
And to that end, the best method to understand what went wrong in our case is to check similar events that had better outcomes, two cases will be used as comparison references in this study, the Daini Nuclear powerplant, as well as the impact of the said disaster (Fukushima) on the public Chinese opinion regarding nuclear facilities and how tolerance towards all kinds of mistakes or even natural threats dropped to an unprecedented level.
After finding out what are the different aspects that went wrong, taking into consideration the different circumstances for each case and comparing the similarities and analysing our case with the provided case studies to find flaws and mistakes, we then will check if the set criteria is satisfied with the changes made in order to decrease the losses of life and material to satisfactory levels (usually in different scales, close ratios to the case studies at hand taking into consideration the country and time of disaster difference), if so, the recommendations, the main obstacles and opportunities for the optimal preparedness and response model possible would be dictated.

2. Literature Review

Japan is a country that has one of most dangerous earthquake hazard probabilities, as throughout history, this geographic spot had an unfortunate record with earthquakes, as the strongest earthquake records ever recorded are from that area, and given that the country has very little area real estate, solutions were invented to solve the ever increasing demand for energy in all its forms, mostly, electricity, and one of those was nuclear powerplants, they were very efficient, small, and overall an invaluable addition to the power generating facilities in the country, the issue that we want to discuss here though is the deadly combination of nuclear powerplants and any factor of instability, natural disasters count as the number one dangerous factor here, especially earthquakes, hence, the unfortunate events of 2011 took place, and here we would like to investigate what made it a very painful experience, especially when a very similar one took place at the same time not very far away at the (Daini Nuclear powerplant) but the results weren't as disastrous.

Fig 1. A Nuclear Map of Japan. Source: en.wikipedia.org/wiki/Nuclear_power_in_Japan

3. Nuclear Powerplants and Vulnerability to Disasters

Nuclear powerplants require a great deal of stability, as the core where the interaction takes place demands the cooling systems to be always running, or an overheating could happen, and a melting nuclear core is the nightmare that had terrorized all countries on earth several times in the last century.

3.1. The Fukushima Daiichi station

This is the powerplant we want to discuss, it is located east of Japan, it was generating about 1.6 % of Japan's total electric capacity at the time (in 2011 Japan had 282GWe being Produced).

3.1.1. Capacity, Properties, and timeline.

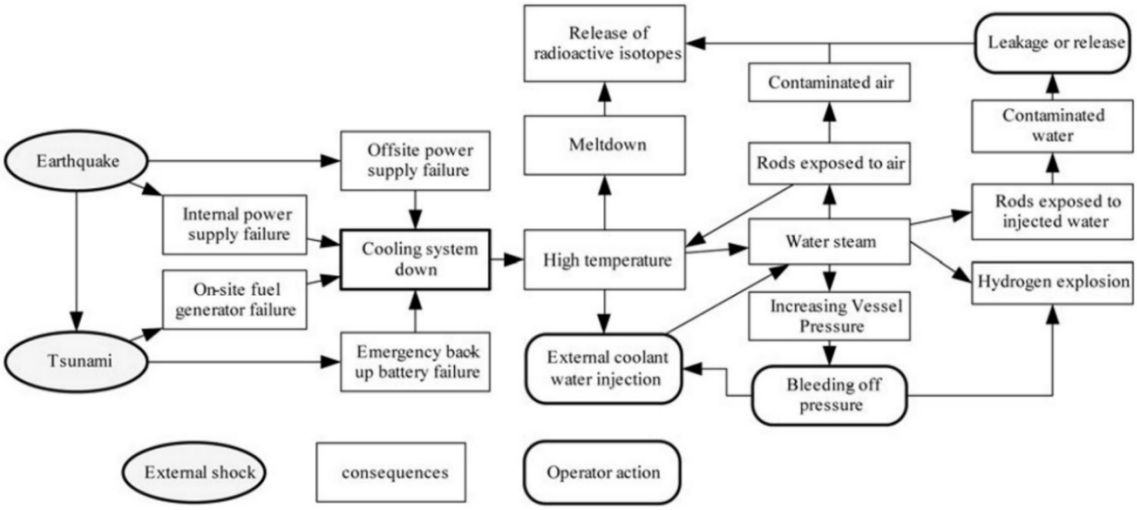
The full capacity of the powerplant was 5,306Mwe when all 6 of its reactors are running, and after the tsunami wave hit, it damaged 3 of the station's 6 reactors (1st(439MWe) – 3rd(760MWe) – 4th(760MWe in the three following days, and the fourth reactor (reactor 2)was heavily damaged through the next (3 – 4) days, the remaining 2 reactors were already shutdown when the event took place, but they were partially damaged still, even though their level was relatively higher than the rest of the reactors, given that they were within 20km evacuation area (that is still active until now) made reaching them problematic.

Even though the fourth reactor was in an unloaded core state, but it shared the same exhaust channel with the 3rd reactor, and when the 3rd reactor was dry and its core began to meltdown, the radioactive hydrogen was transferred to it (reactor 4 core) and caused it to heat up and eventually explode without the proper cooling needed.

There were someone attempts to cool the reactors using sea water, but unfortunately, they were not the most practical solution, as it wasn't enough to tip the scales.

in mid of December 2011, it was announced that the three reactors in official cold shutdown, which means that the cooling water going through the core is not evaporating anymore and is coming out of it with a degree less than one hundred Celsius.

it was estimated that the melted cores will be in that state for the next 4 decades until they can be decommissioned.



Illustrative chart of the 2011 Fukushima nuclear crisis
Table. 1, Source: (Norio et al., 2011)

3.1.2 Response

A wall of ice was established around the powerplant to prevent radioactive materials from escaping, but they still do.

For the next four decades (until the cores are completely cold) Japan has to always pump water into the core and then filter it (because we don't want radioactive water being dumped in the sea for the next 40 years) before sending it back to the sea, and for that purpose they built the biggest, most expensive cooling and filtering system as you can see, (2004 – 2012 – 2019) respectively

the red outlined areas are all water tanks and filtering systems.

Fig. 2. Source: Google Earth

In all nuclear scenarios, every second is imperative, and decisions must be made with high delicacy and efficiency, which leads us to the importance of each step that was taken to try prevent a larger disaster than what we already got, a major one which had even a political aspect later was, pouring the sea water into a reactor core, because once it was done, the reactor of concern is considered irreparable, and that in itself is a huge economic loss to the country.(Norio et al., 2011)

4. Impact of the Disaster in Different Fields

The disaster had sadly laid its shadow on many aspects of civil life, and in the next section we will be presenting some of the most impacted sectors:

4.1. Economically

The Japanese Economy took a sever hit, the losses of the tsunami wave were estimated to be about 360 billion USD, being the most expensive natural disaster to ever take place, forced more than 600 companies in 2012 to declare bankruptcy, as well as the loss of the buildings, and many of the cars manufacturers in japan had to stop producing their products because of the Tsunami wave, many buildings were either affected by the earthquake (190.000) among which are buildings that are completely destroyed by it (45.700), as well as many of (23.600) hectares of agricultural lands were corrupted.(Norio et al., 2011)

4.2. Human Lives

The tsunami waves took about 15,890 people's lives, and left the rest in case of trauma, either from losing their properties, and some who lost family members or friends.(Matsubara et al., 2014)

As its noticed that depression rates among the tsunami survivors increased dramatically, which is represented as a psychological burden, it hits hardest on women and older people especially the ones living in their damaged houses or the people that were forced to live with more than 5 people, as well as the lack for basic services in the affected areas contributed to the deterioration of the psychological state of the residents. (Matsubara et al., 2014)

Of course, there have been some models regarding the fatality ratio (number of deaths in an area as a proportion of its population) of the tsunamis trying to understand its relationship with the arrival time of the tsunami, the different areas geographical properties, gender, age, and evacuation procedures followed.(Latcharote et al., 2018)

Evacuation process was different with individual cases depending as we discussed on age and gender, as well as previous experiences with disasters, the perception of one's house safety, and other variable reasons.(Latcharote et al., 2018)

As noticed, most of the tsunami waves took between 20mins until 70mins after the earthquake to hit the shoreline, as we can see that this value is not proportional to the death toll, unlike the height of the tsunami waves which was proportional to the fatality ratio.(Latcharote et al., 2018)

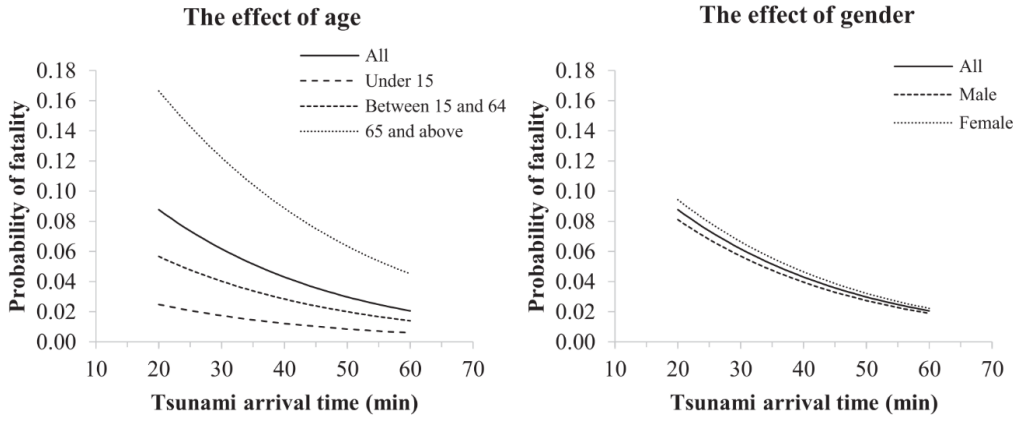


Fig 3. Source: (Latcharote et al., 2018)

As we can notice that the fatalities among people who are older than 65 is higher than the rest of the statistic group.(Latcharote et al., 2018)

4.3. Ecological impact

The lack and pattern less of tsunamis made it hard for us to obtain accurate data about their impact on ecosystems, so after the great eastern Japan earthquake and tsunami, a study was conducted regarding this matter, and it was found that when a tsunami hits a beach or a coastal area, it actually enriches the species of plants in that area, in our case a sum of 103 plants were found in the place, about 34% of which were coastal species, it's important to notice here that this ratio significantly dropped after the tsunami, and the rest 66% were non-coastal species, but the interesting part is that more than 10 new species appeared after the tsunami, reasoning of which is thought to be because of the soil accretion.(Hayasaka et al., 2012)

A recent study also shows that the concentration of radionuclides (tritium and equivalents) in groundwater had rose in two examined water sources within 35km radius of the Fukushima Daiichi nuclear powerplant, the amounts of these radioactive materials found in the water is explained by the penetration of a soft and fractured bedrock which allowed them through, as well as the combination between underground water with new water from whatever source (irrigation, fall water…) that had high concentrations of these materials, and it was estimated that this water

would take between 10 and 26 years until it's possible to obtain usable water from the mentioned sources.(Sakakibara et al., 2019)

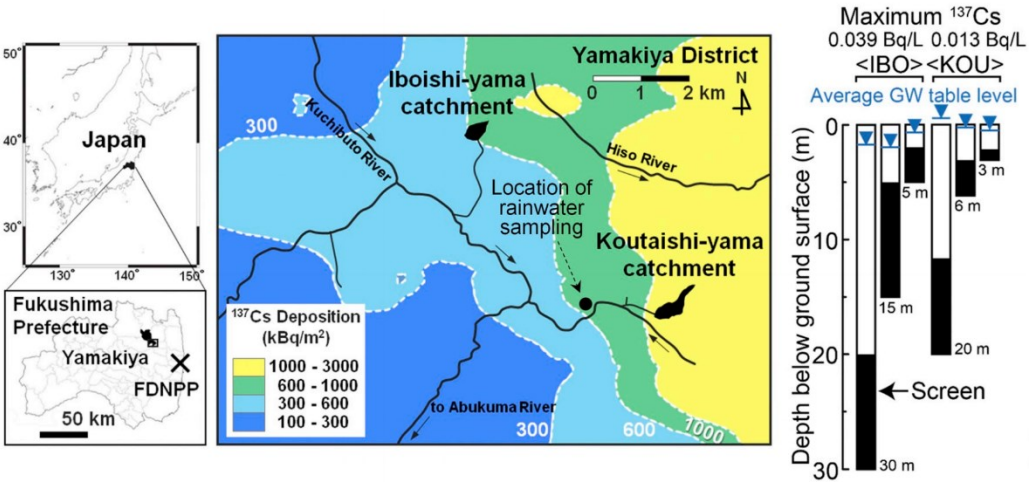


Fig 4. Source:(Sakakibara et al., 2019)

4.4. Energy issues

The tsunami waves caused the Fukushima nuclear powerplant to fail causing radioactive radiations to be released at extremely elevated levels, the power plant consisted of 6 reactors at the time and was generating 4.5GWe of energy.

4 of the reactors were seriously damaged (they summed up to generate 2719MWe) and TEPCO decided to not restart the remaining 2 reactors.

As they will have to dismantle the melted reactors, which will take roughly 4 decades, The melting of three reactor cores in the Fukushima powerplant forced about 160,000 people to leave their contaminated homes, and about 60,000 are currently living in temporary housing.

After the nuclear accident all aspects of environment were exposed to radioactive volatile materials, monitors were installed in various places around the affected area to observe the quantity of radioactive materials in each area as well as knowing the distance they reached.

Monitors like air dust monitors, drinking water monitors were installed, and from those monitors points we acquired the following results (Yamaguchi & Kunugita, 2019):

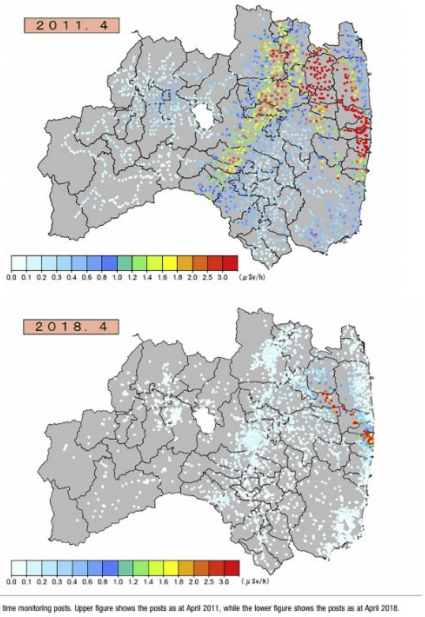


Fig 5. Source: (Yamaguchi & Kunugita, 2019)

Even cattle that wasn't close to the area of the accident was affected, as it was found in its meats after 4 months of the accident, which was explained later by the food the cattle were eating was exposed and had in fact contained a ratio of radioactive materials.(Yamaguchi & Kunugita, 2019)
due to these ratio's, cancer and other diseases occurrences increased affecting the wellbeing of the people in the affected areas. (Yamaguchi & Kunugita, 2019)

5. Preparedness and Response

Considering the BBG (Build Back Greener) approach keeping in mind that we need to be better prepared for any possible future disasters, most of the coastal areas correlated with tsunami need the biggest scale rebuilding process, problem here is that rebuilding needs decades of observation for damaged area to make sure that its contamination has dropped down to liveable values, the BBG concept aims basically for three targets, 1st of which was to make DRR through eco-solutions clear which encourages more country's to take the same approach, 2nd is to increase the awareness of the stability of green approaches and their resilience while making the land scape greener and more beautiful, 3rd make sure that it's clear that it takes a qualified planner(s) to be able to realize when a green(er) solution could be applied and beneficial, because not all cases benefit from this type of solution.(Mabon, 2019)
As in the conducted study it's been shown that this tsunami caused tremendous damage to the coastal area, but this damage was a price for a lesson must be learned in the pursuit of making more resilience coastal communities, as numbers show that tsunami waves with height lower than 2m were damaging but with no devastating outcomes on households, waves with height more than 6m are considered ruining to households.(Koshimura et al., 2014)
In the figure we can notice a suggested model of a coastal protection wall, in the Sendai city example we can see that it supposes having several layers of protection to weaken any waves that might come.

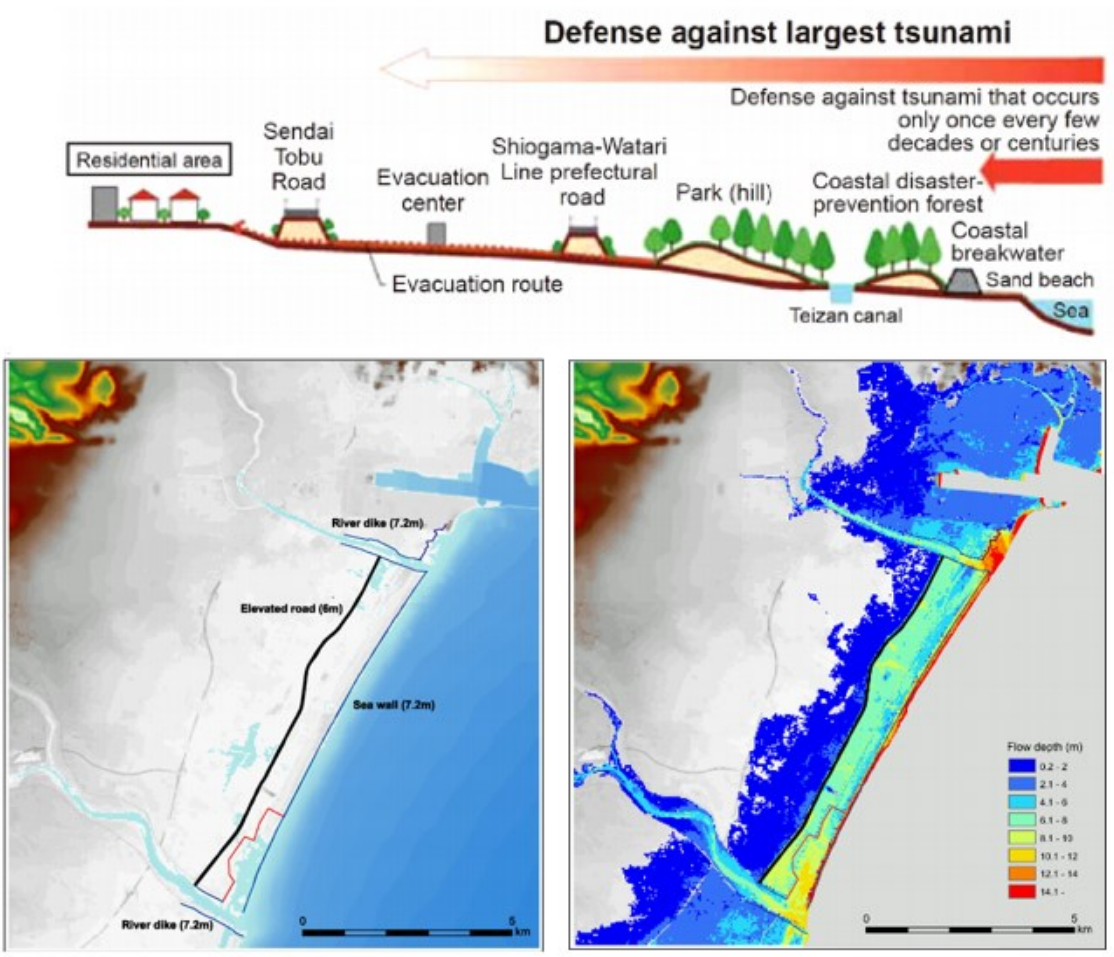


Fig 6. Source: (Koshimura et al., 2014)

The tsunami speed reached about 8m/s up to 1km into the land with inundation of more than 6.3m had the ability to wash away everything in its way, which is why its advised to consider those numbers while re-zoning the area for any future events. (Koshimura et al., 2014)
Following the GEJE there have been numerous studies regarding the need to improve the earthquake detection systems to make them able to anticipate the velocity, direction and estimated time of arrival of a tsunami resulted by an earthquake, the approach is based on improving the q-factor aka (Tsunami detection function) which is a factor related to the changes in water velocity at sea, and by using this factor with the radar attached equations, it's possible to obtain graphs regarding the speed of the waves correlated with the time of the earthquake, as we can notice from the graphs, when the q-factor's value starts dropping and becomes negative, it's an indicator that the tsunami waves speed is dropping, which can only take place in case the tsunami isn't aimed towards the shore anymore.(Chaturvedi, 2019)

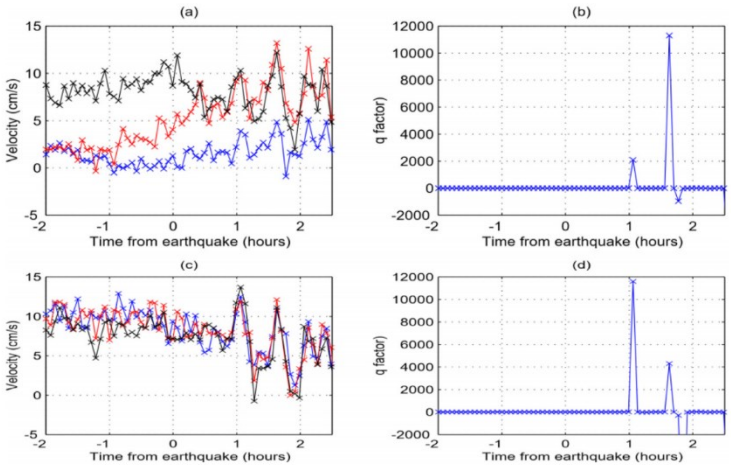


Fig 7. Source: (Chaturvedi, 2019)

There was a problem that didn't help at all when the disaster took place, it's that Japan has no guidelines to manage a disaster situation traffic, which caused many jams that were in the best interest of no one, so after the disaster this issue was noticed and there have been some steps to take care of it and make the overall responding process more sustainable (Nakanishi et al., 2013)
So, in order to solve the problem of a post catastrophic traffic issues we need to understand what are the needs that arise after such an event, to be able to solve them one by one, before the disaster took place, the municipalities had no idea nor statistics regarding the roads' limitations in a case of a tsunami, which made conducting an emergency strategy not possible for them.(Nakanishi et al., 2013)

6. Case Study

In these sections we will be comparing the Fukushima Daiichi powerplant event to other similar cases with similar conditions but different outcomes (less disastrous one)

6.1 The Fukushima Daini Station

A smaller nuclear power plant than the Fukushima daiichi power plant located south to it producing 1067 MWe which is less than 1% of Japan's total power generation capacity at the time.

6.1.1 Timeline and challenges

This station faced a very close fate to its 10km neighbour Daiichi, but with some more luck and preparedness it had better outcomes in comparison to our main case.
In this station and after the tsunami they still had some undamaged diesel generators, the problem in this powerplant however was that the wiring of the station was completely destroyed and the backup diesel generators were to an extent useless as they had the same weaknesses as the main system, which made them more of a secondary system rather than a backup one (Norio et al., 2011) until 1 more day when they got cables and wired the water pumps by hand and had to wire very thick cables to an estimated distance of 5.2km.

6.2 perception of the event

the Chinese perception of nuclear powerplants after the Japanese disaster, how the people began to realize that nuclear accidents are more serious than anything else, therefore in the coming graphs we will be able to see that the public tolerance towards nuclear events had dropped immensely, regardless of the cause of the accident or whose fault it was, following the GEJE disaster, while taking the people's opinions, 5 main perception factors were measured (Acceptance, Knowledge, Perceived risk, Benefit and Trust).(Huang et al., 2018)

It is debated that a part of the problem is brought back to two main reasons, 1st of which being that when the disaster happened municipalities of the damaged areas were extremely understaffed, which left them paralyzed in front of the huge event that was completely out of their capacity, 2nd of which is that at the time, Japan didn't have such thing as decentralized disaster management infrastructure distributed around the country, which had forced to contact Tokyo to get their every move, a responsible move that had to happen because of the chain of command, but it delayed everything and made the situation that may could have been handled faster, an unsolvable disaster.(Aoki, 2016)

And as for our case we've seen what happened in the response period, now we need to look at some other levels as well.

Basically, Japan is a country that has always been hungry for energy (worlds 5th energy consumer) and the 2011 accident didn't help this issue at all, in fact it made it worse, this disaster affected Japan on both short and long terms dramatically, which is something explained by many explanations.

7. Results

Having all its nuclear powerplant near the sea, made them all exposed in the future for such an incident.

Which actually forced The Capital "Tokyo" to adopt a new energy providing approach, the old one, which as we know requires lots and lots of fossil fuel, which made it worse – but safer anyway- for Japan on two aspects, Economically as the prices of fossil fuel were sky-rocketing, of course Japan has no sources of which they can acquire fuel whatsoever which held them forced to buy all the amounts required as they can't produce any.(Vivoda, 2012)

as well as regarding the greenhouse emissions which forced Japan to be in a situation they didn't want to be in as they had signed the Kyoto Protocol, which is a protocol that took effect since 2005 but was created and signed on since 1997.

It renewed Japan's needs for Fossil fuel and in that year specifically, Japan's needs of fossil fuel went 25.5% up, which is not a small number at all, which made the imported fossil fuel make up to one 3rd of Japan's total importing's, as nuclear powerplants were producing up to 24% of Japan's production of energy (Vivoda, 2012) of course before the 2011 disaster they were looking to increase this number up to 40 – 50% by 2030, unfortunately, they had to withdraw this offer.

As we can see in figure 10, the left side is the energy production sectors in Japan pre-2011, and the right one is the after 2011.

With a quick look we can notice that nuclear energy lost a huge share that was replaced by the fossil fuels (Oil). (Vivoda, 2012)

the energy future in Japan is affected by three factors which are:

1. Public opinion
2. Energy policy Making system
3. Relative energy prices

Japan as a country is one of the biggest energy consumers in the world, and as we know, up to the Fukushima accident Japan had been using nuclear energy to satisfy its needs, what brought Japan to this type (Nuclear) of energy was nothing other than the 1973 oil crisis that made it lose its belief in fossil fuels and turn away from them, but now after Fukushima, they seem to have the same trust issues that they had in 1973, only this time its with nuclear powerplants, this made it important for them to once again find an energy source that can satisfy their needs as well as prevent their history of power supplement to reoccur again, they found their answer in renewables, especially in solar PV over wind even though that cost wise, wind is far cheaper than solar PV, as Japan is considered as one of the biggest manufacturers of solar PV, in Year 2000 Japan had almost half the share of their production globally, which made them their no.1 manufacturer, Japan had to face it's energy transition in a rather early time, and issue that all major countries are going to have to consider at some point.(Li et al., 2019)

8. Discussion

Japan is in an active seismic area, and yet it had the nuclear energy approach, the country officials knew that at some point, a disaster would come along, and to an extent they were ready up to a certain scale.

Japan did have a plan to respond to disasters, but the problem was that they weren't prepared to answer to something this big, something they never thought would happen.(Norio et al., 2011)

Another very important point was the medical attention needed after such a disaster, of course the need for medical care centers increased dramatically after the disaster took place, as well as the most of the affected areas lost most of their medical capacity when the earthquake hit, which made the need for help a very big issue, and taking care of such issues, and knowing their statistics, makes us more aware and gives us better preparing capability for future events(Omama et al., 2018) The main aim of the stations that were installed in the damaged area's soon after the earthquake was to provide first aids for the affected people in the flooded/affected area's while the main hospitals and centers were restored(Omama et al., 2018) Even though these mobile and installed stations were providing first aids as best as possible, it took more than 7 days for them to be deployed in their required areas as it was
also noted that 30 – 50% of the consultations were to require medicine, which shows an advanced awareness of the residents of the damaged municipalities.(Omama et al., 2018)
As there was an effect on the people on the long-term as after one year of the great eastern Japan earthquake, the ratio of disabilities among the people increased noticeably(Tomata et al., 2015) As it is a good place to consider whether the rising number of disabilities is caused by the radioactive materials released by the disaster or not(Tomata et al., 2015) As well as the spreading of some kinds of infectious diseases that were reported in the period following the tsunamis, due to some evacuation conditions and some questionable drinking water in that level, lack of food, which caused these issues. (Takahashi et al., 2012)
So, in terms of preparedness, we will be talking about individuals to begin with, it is a given fact that elderly people are harder to evacuate that all other categories, and they tend to find the shelters that are closest to their living place, but they face an issue actually being warned by the evacuation alarm which can cause a problem. (Sun & Sun, 2019) also, some differences were noticed depending on gender, as men are more responsive to an evacuation alarm than women, especially in nighttime, which makes it harder for a unit to evacuate effectively. (Sun & Sun, 2019) it is also that people that are alone or single are less responsive to an evacuation warning than a family, the previous cases and categories are depended on statistics, which can give us an impression about a certain society's preparedness for disasters and its responding capacity. (Sun & Sun, 2019) So, in the preparedness stage we need to realize that delivering the warning in right manner could save many lives, because as we've seen, some people just didn't get the chance to know they had to evacuate in the first place, which is a very serious problem.(Naylor et al., 2018) so, the efficiency of a warning is as much ratio of the people that can receive it, as well as its capability to get people to evacuate rather than just ignore the warning. (Naylor et al., 2018) warning systems are one of the most important aspects in a disaster scenario, therefore we'd like to present some recommendations that could help improve future warning systems ability to reach out for more and more people involving the people in the deciding process of the alarm system, knowing that there isn't one kind of a warning system that is applicable to a whole country, and that every group of people should have their own warning system that is effective on them, as well as some of the upcoming technology isn't showing much promise in helping to spread such an info. Also, making sure that all the sirens and electricity dependent systems are always operational, so they are ready when the time comes. as it can be beneficial involving the community in spreading, planning, such alarms. (Naylor et al., 2018)
It is noticed that tsunamis during the last 20 years have caused gradually more and more damage, the reason for that is the more expansion of residential and different activities that are taking places near coasts, which proves that a globalized tsunami warning could prove more useful, effective, and precise and could save many lives, of course in any community (especially the Japanese one) education about and awareness of the disaster can prove to be the most cost, life effective method among them all. (Imamura et al., 2019; Naylor et al., 2018)
as illustrated in Fig 18, they used 3 surveys, each of which serving a different goal, the 1st survey consisted of two sections, 1st of which contained general questionnaire regarding some demographic questions, as in the 2n section there were disaster perception questions as for the 2nd and 3rd surveys, an additional sector was added to the surveys, regarding the acceptance of the happening of a nuclear disaster.(Huang et al., 2018)
we can notice a spike in the 2nd factor in the 2nd survey which was conducted in the period following the EJGE and it targeted the population around the closest Chinese nuclear powerplant to Fukushima Daiichi nuclear powerplant.(Huang et al., 2018)

9. Conclusion

In those two cases Japan couldn't have possibly been able to apply a waiting strategy, because when we talk about nuclear powerplants, every single second matters, so what they were forced to do and what was the rational thing to do at the time and in the following period was a mix of a phased strategy and an umbrella strategy, as they 1st had to respond to the problem at hand with whatever materials at hand, then changed their strategy to containment after the urgent part of the disaster was handled by the phased strategy.
Reaction window was very narrow as the 1st tsunami hit 65 minutes after the earthquake, even though they had already shutdown the reactors, the problem was that the nuclear reactors shutdown period Is around 24 hours, but

in this case they had less than one, so one solution here could be them having better protection systems for such a sensitive facility.
Expected waves were not higher than 3.5m while the real waves were more than 15m high
The protection wall in front of the power plant was very short to stop such a wave, it was only 7.5m high, so that gave them the feeling of false protection, while they were far from this, no one knew though, until it was too late.
At the time of the occurrence, why did they need to bring everything from Tokyo which was about 265km away and with the tsunami wave destroyed areas, the actual travelling time between them was higher than anticipated which was about 3.5 hours in normal conditions.
Japan had never seen in the recorded history of earthquakes (since 684) an earthquake of a magnitude of 9.0 Mk, and they do still have many earthquakes happening that are above 6 Mk.
A tsunami wave of this destructive capacity is the 1st since 1703 where a tsunami wave also following an earthquake took the lives of 110.000 people.

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