Wind farms: harvesting energy on shaky grounds and in stormy seas

Renewable wind energy is one of the fastest growing sectors in the power generation industry worldwide, with installed capacity set to nearly quadruple by 2030. But many of the future wind farms will have to be built in areas exposed to earthquakes and storm gusts. What does this mean for the reliability of our energy supplies?
To achieve economies of scale, wind parks often comprise 100 or more individual units. If they are located in areas that are exposed to earthquakes or severe windstorms, they may well suffer damage ranging from broken blades or nacelles to entire towers snapping in two.

In such cases, you as a wind farm operator or owner face not only a huge repair or replacement bill, but also a loss of revenue, as events of this kind tend to affect not just one but many units.

Technological revolutions such as a change in energy supply invariably entail risks – and these can be managed. The wind energy industry is working on these topics and Swiss Re is contributing its expertise with insurance solutions for construction and engineering projects.

This publication is part of our ongoing support of the renewable energy sector. The following pages show you where the hazards are, what can be done to mitigate them and how insurance can help to cover the residual risk.

Your revenue streams and wind farms can be protected against even the most severe events. If disaster strikes, insurance payouts stabilise your balance sheet and provide the funding to rebuild your turbines.

This makes both you and society at large more resilient, because insurance can ensure that clean power will keep on running while keeping the effects of climate change in check.
Moving to dangerous grounds

According to Bloomberg New Energy Finance (BNEF), wind and solar will account for 48% of installed capacity and 34% of electricity generation worldwide by 2040, compared to just 12% and 5% today. Installed solar will grow 14-fold and wind capacity nearly fourfold.

Huge investments will be necessary to meet these goals. By 2040, USD 10.2 trillion will be invested in new power generation capacity worldwide, according to BNEF. Of this, 72% or USD 7.4 trillion will go into renewables, with solar taking USD 2.8 trillion and wind USD 3 trillion.1

Many of the easily accessible areas for wind power plants have already been developed, so that many of the new facilities will need to be built in less convenient areas. Large urban centres around the world have the greatest need for energy. Today, more than one in two people of the world’s population already lives in urban areas, a share that is expected to increase to two out of three by 2050.2

Ideally, power plants should be situated close to the new urban centres, and fortunately many of these are in areas where sufficient wind is available – especially in Asia. The downside is that many are also located in parts of the world where earthquakes are common and wind gusts much higher than desired for normal operations – as shown in Swiss Re’s publication “Mind the risk”3. Combine the two hazards and the situation gets worse, putting at risk a significant share of the USD 3 trillion investments and the resulting revenue streams by 2050.

Modelling for the worst

Still, we have successfully built in areas that face severe natural threats in the past – otherwise these cities would not be standing today. Over its more than 150-year history, Swiss Re has insured and paid out for losses in exposed areas all over the world – be it for severe storms in Europe or for major earthquakes like the latest one in New Zealand in 2016.

Our long history and experience flows into the risk assessments and modelling we run to insure new risks such as wind farms in exposed areas. For the seismic hazard, Swiss Re experts together with the Danish Technical University looked at engineering, exposure and vulnerability aspects of major wind farms from today up to 2030.

3 http://www.swissre.com/library/expertise-publication/Mind_the_risk_a_global_ranking_of_cities_under_threat_from_natural_disasters.html
Wind power in 2015 and in the future

The world map shows today’s wind farms and their future growth, it is based on an extensive review of current data. Major new developments will be made both onshore and offshore in areas exposed to earthquake and peak gusts.

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Where the exposures are

Areas worth noting are the accumulations in Asia, along the Ring of Fire around the Pacific, and in the great collision zone between India and Asia where exposures and seismic hazard are high. At the same time, these areas are prone to frequent and violent typhoons, whose wind speeds pose a threat to expensive installations.

Seriously affected farms could trigger severe business interruption in the fast growing economies of the entire region. And the costs to repair or replace damaged turbines would also need to be covered. Just how high could the bill be?

Harvesting model outcomes for more resilient wind farms

To answer this question, we modelled the exposures for wind globally and for earthquake in China based on the existing data we have acquired over the years. The result with seriously damaged farms is shown below:

A 200-year event could trigger a market loss of several billion USD depending on where it strikes. A 50-year event could also easily breach the USD billion threshold in a given market by 2030.

These calculations show that potential future exposures will be huge. What can be done to make our energy supplies more resilient?
Managing risks when moving on to new ground

If we want to make wind power more resilient, we must first look at the turbines. And it turns out, we do not know as much about them as we might think. First, wind power has only really been used at an industrial level in recent decades; second, new, larger and more powerful turbines are developed at ever shorter intervals. This means that, similar to the IT industry, rapid innovation cycles are constantly generating new risk profiles for wind farms.

Since wind turbines are fairly recent installations, there are only very limited records on earthquake damage to wind farms. Reports document only two cases related to earthquake damage: one in Japan in 2011 and one in California in 1986.

At the Painted Hills wind farm in California, while none of the 65 turbines were knocked down, 48 of them sustained minor structural damage requiring repairs. The event also triggered substation failures, highlighting the potential for grid failures.

The 2011 tsunami in Japan damaged one out of ten turbines, partly as a result of soil liquefaction. As in California, the transformer system on the coast was affected by the tsunami, again highlighting potential losses from grid failure.

Various storms have led to large losses among wind farms. For example, Super Typhoon Soudelor brought down several wind turbines in a wind farm in Taiwan in 2015. And in 2013, Super Typhoon Usagi damaged wind turbines situated directly on the coast in China’s Guangdong Province.

Still, even if there have been only few losses, this does not mean there is no exposure. It merely reflects the fact that to date there are few wind turbines in exposed areas. But if we start building them there, how resilient will they be?

The resilience of wind turbines

Wind turbines have their design challenges. They are top-heavy on steel columns. With the force of wind against them, wind turbines have to withstand peak loads. Damage may occur if the limits are exceeded, and in extreme cases the turbine might come down. So what are the limits with regard to earthquakes and peak gusts?

While studies are plentiful, useful ones for a comprehensive seismic risk or resilience assessment are rare. The Danish Technical University conducted a state-of-the-art review and analysed 155 publications on the topics of seismic design and vulnerability. Nearly 90% of them were published after 2000, indicating increased research activity. Only one full-scale experiment was conducted, with a turbine much smaller than those used today.

Considerations that are important to estimate the seismic risk of wind turbines were often not made. For example, during earthquakes, wind turbines also experience wind forces, and wave forces if they are located offshore. Only very few studies consider concurrent wave, wind and earthquake action on wind turbines. This is insufficient, as it is important to consider all concurrent actions that are present when an earthquake shakes a turbine. This includes wind action, and wave action for offshore wind turbines.

Our knowledge of wind turbines and how they react to earthquake activity and peak gusts is currently not at a level we would like it to be. Research must cover this significant knowledge gap and integrate its findings into risk management aspects as the wind power industry gradually moves into more exposed areas.

6 http://www.windpowermonthly.com/article/1213452/chinese-typhoon-knocks-17-wind-turbines
7 See also Swiss Re’s publication: Moving on dangerous grounds - wind power and earthquake exposures in China, www.swissre.com/library
Managing risks pro-actively

To enable wind parks to keep on running even in severe events, the following should be considered in the planning and design phase:

- Which natural hazards are present at the selected site? Swiss Re’s CatNet® accessible via our website, gives you an initial indication.

- For areas exposed to earthquakes* and peak gusts
  - Time history analysis is the preferable method to predict the non-linear dynamic response of wind turbines subjected to concurrent loads (wind, wave and earthquake).
  - The wind turbine may be in different states of operation, such as normal operation, parked or emergency shut-down. This should be considered in modelling the forces affecting the turbine.

- In earthquake-prone areas, take the following into consideration**:
  - the selection of seismic motion used in the time history analyses, as the selection of ground motion may strongly affect the results of the vulnerability study
  - soil structure interaction, as the soil structure may significantly change the seismic response of the wind turbines
  - additional effects, such as scouring and liquefaction
  - maintenance and deterioration due to corrosion and fatigue

If wind farms in exposed areas are designed bearing in mind the considerations above, the probability that they will withstand a severe event is high. In addition, the enabling infrastructure needed to make repairs, such as cables, substations and access roads for onshore facilities, should also be designed taking into account natural hazards. Wind farms need special repair equipment, and if they are not accessible for days, this extends business interruption.

This issue is even more acute with offshore farms, since high waves and bad weather may make it impossible to access a damaged turbine quickly. Also, offshore wind farms include additional equipment (e.g. offshore and onshore substations), all of which must work to keep a farm operational. The failure of just one part of the equipment can create a bottleneck and bring production to a standstill. For all these reasons, the repair of offshore wind turbines is more difficult and more expensive.

Many of the risks can be managed along the value chain, but substantial residual risk remains, and insurance is the right instrument to handle this.

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* [http://www.swissre.com/clients/client_tools/about_catnet.html](http://www.swissre.com/clients/client_tools/about_catnet.html)
** [http://institute.swissre.com/research/library/Moving_on_dangerous_grounds_SRI.html](http://institute.swissre.com/research/library/Moving_on_dangerous_grounds_SRI.html)
Safeguarding properties and revenues via insurance

The insurance offerings available to wind farm operators cover the entire value chain.

Planning and construction: Swiss Re’s engineering policies insure your facility during the construction phase. Depending on the cover you choose, it insures only property and/or loss of revenue due to delayed start-up.

Operation: index-based “lack of wind” coverage is available. It is triggered if a certain pre-defined threshold is met, protecting the revenue streams of corporate\(^{10}\) and reinsurance\(^{11}\) clients in long windless periods or if you have to shut down in case of a storm.

Natural catastrophe coverage protects your farm against damage resulting from storms, floods, earthquakes or wildfires. Depending on the cover you choose, it can also be limited to property and/or loss of revenue due to delayed start-up.

The road ahead to a clean energy future

The transition to renewable energy supplies is underway, as the exponential growth rates show. Climate change and air pollution mitigation will drive this process forward in the years to come.

In many countries, wind will be a key component of the new mix of energy supplies. The process is advancing rapidly, and technological developments in this field will accelerate even more. As a case in point, the first floating wind turbines were installed off the coast of Scotland in 2017.\(^{12}\) This is just one example of a technological leap that will bring new opportunities but also new risks – just think of the cables and substations for a floating wind farm far offshore.

To get investors to buy into this new technology, they need the assurance that their investments are safe and revenue streams are assured. Part of this assurance comes with the design, and for the rest, the insurance industry can provide the coverage investors are looking for.

Dealing with technological change is part of the DNA of the insurance industry. We have over 150 years of experience in insuring technological innovation. Let’s work together in applying it to wind power to ensure our future energy supplies are reliable and resilient.

\(^{10}\) https://corporatesolutions.swissre.com/innovative_risk/weather/
\(^{11}\) http://www.swissre.com/library/factsheets-publication/protection_against_resource_volatility.html
Annex

We have a long history of developing, maintaining and advancing our own proprietary, state-of-the-art risk assessment models. A risk assessment model is nothing more than a simplified representation of reality. Natural hazard models use the virtual world of computers in an attempt to simulate natural catastrophe losses expected in reality. These virtual worlds consist of four different basic sets of data:

**Hazard**
The hazard component contains the physical footprints of realistic catastrophe scenarios. This can be, for example, the maximum peak gusts during a tropical cyclone or the peak ground acceleration during an earthquake. It allows to assess where, how often and how severe potential events can be. Because the historical record usually is not sufficient to assess this question in a consistent and robust way, natural scientists simulate hundreds of thousands of artificial but still realistic (so-called probabilistic) events.

**Vulnerability**
The vulnerability component describes the damage (or loss) ratios as a function of the physical intensity (e.g. peak gust, ground acceleration). Generally, the loss ratio at a given intensity depends heavily on the risk characteristics. In the case of a wind turbine, such factors as the design standard, age, safety mechanisms and the foundation play a major role. This becomes evident from both loss experience and engineering considerations. In addition to the expected loss ratio, the spread/uncertainty is also taken into account.

**Value distribution**
The exact location and type of an insured object (e.g. a wind farm) are very important factors determining both hazard and vulnerability. In order to be able to put an absolute amount on the loss, the value of the insured objects also needs to be known. In addition, the value distribution determines how far the expected losses of the risks in a given portfolio correlate for a given natural peril: risks located along typical storm tracks are likely to suffer damage from one and the same cyclone. If the value distribution is tracked over time, this also allows for accumulation control.

**Insurance conditions**
Insurance conditions, including deductibles and limits, are important tools allowing the re/insurer to keep its share of any loss within reasonable limits. These conditions may apply to an individual insurance cover or to several insured interests in the same location. Obviously, such conditions must be taken into account when computing absolute expected loss amounts.