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Leading Edge erosion and pollution from wind turbine blades

5 th. Edition - English

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"THE TURBINE GROUP" JULY 2021

Preface

We have put together a report on an under-communicated topic; emissions of microplastics and possible toxic compounds from Wind turbines.

Our estimates for emissions are based on the report "*Rain Erosion Maps for Wind Turbines Based on Geographical Locations: A Case Study in Ireland and Britain*" University of Strathclyde, 2021.[1]

It is difficult to find good and impartial sources for the problem of emissions from wind turbine blades. Reports that have been published and research that has been done on the topic are most often carried out by authors who have their most important source of income from wind power, such as reports from www.epoksy-europe.eu. The report from Strathclyde is one of the few reports dealing with the volume of emissions from the turbine blades. Just days after our first edition was released the University of Strathclyde announced "*Aker Offshore Wind, Aker Horizons and Strathclyde to collaborate on accelerating recycling glass fibre products*".[2]

The University of Strathclyde is one of three universities in Glasgow, Scotland. The university has its roots in Anderson's Institution which was established in 1796, and gained status as a university in 1964. It was ranked 38th out of 126 British universities on the Complete University Guide's list for 2016 and number 33 out of 119 British universities at The Guardians 2016. -list. (Wikipedia)

We have estimated emissions from the leading edge of wind turbine blades by calculating the mass loss from Norwegian wind turbines based on the report from the University of Strathclyde.

Already in 2013, rotor blades from wind turbines accounted for 27% of Europe's consumption of epoxy.[3] Depending on production method the epoxy in rotor blades contains as much as approx. 33% Bisphenol A.[4] Nevertheless, there is remarkably little available information on microplastic emissions from turbine blades. However, there are many reports from the industry that focus on wear and maintenance. This indirectly confirm the issues we describe.

Bisphenol A is on the «Norwegian priority list of dangerous substances». These are chemicals that are considered to pose a serious threat to health and the environment are placed on the Norwegian priority list. The list serves as an important tool for which substances the authorities should work specifically with, and it gives an important signal to the business community that these are substances where it is important to work for reduction in use or emissions.[5]

In the 3rd edition, some references were replaced so that now the reference goes directly to main sources where they previously went via our report. For example, footnotes 2 and 3. In the 4th edition, some typing errors were corrected and an updated calculation of erosion for the Norwegian coast were made.

This edition is in English and we have added facts and information given to us (29. April and 4. May) from the researchers of the Strathclyde rapport. We understand the facts and information to support our estimates and calculations.

We would also like to thank and credit Veronica Metcalfe for solid help with this English edition.

Stavanger, Sogndal and Trondheim and 08.07.21

Bård-Einar Rimereit, Jan Erik Weinbach og Asbjørn Solberg

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1 https://link.springer.com/article/10.1007%2Fs40735-021-00472-0
2 https://www.strath.ac.uk/whystrathclyde/news/akeroffshorewindakerhorizonsandstrathclydetocollaborateonrecyclingglassfibreproducts/
3 https://epoxy-europe.eu/wp-content/uploads/2018/11/Epoxy_Socioeconomic_Study_Main_Findings_August-2017.pdf
4 https://www.epoxy-europe.eu/wp-content/uploads/2015/07/epoxy_erc_bpa_whitepapers_wind-energy-2.pdf
5 https://www.miljodirektoratet.no/chemicallist/61?listcasnr=80-05-7

Content

Summary

There are examples from both the UK and Denmark that after 5 years you either have to make very large critical, costly repairs such as at London Array Park or demolition / replacement as at Anholt in Denmark. Both locations with wing diameter of 120 meters.

Experiments carried out at the University of Strathclyde show that a rainfall with pure particle-free fresh water of 50 mm pr. month results in a mass loss of 0.037% pr. month and a rainfall of 500 mm pr. month gives a mass loss of 0.199% pr. month. The wear with seawater (3.5% salinity) is 40% greater[6].

> A turbine blade is simply explained as fiberglass mats, epoxy resin and hardener.
>
> Epoxy, in contrast to polyester, contains 33% Bisphenol A which is considered very harmful to health.
>
> The blades of a 4.2 MW turbine for areas with harsh weather have a diameter of 130-140 m and the total weight is just under 60 tonnes, with longer blades they weigh well over 60 tonnes each.

We estimate a total weight of 60 tonnes per. turbine.

We estimate the total of exposed leading edge (LE) weight to be 700 kg.

Many places along the Norwegian coast have annual rainfall of approx. 2,500 millimetres.

This gives us the formula for wear and tear: $f(x) = 0.979\,\% * \left(\frac{diameter}{100}\right)^{11,4}$

And an estimated annual emission of microplastics of approx. 62 kg per year per turbine.

And 20 turbines more than 1.2 tonnes each year and 31 tonnes over 25 years.

In Norway there are close to 400 turbines with a wing diameter of 130 meters or more. Estimated total emissions from these 400 turbines are 25 tonnes a year.

Over the course of 25 years, this amounts to an estimated 620 tonnes!

We point out that we have calculated the annual precipitation as rain. If the precipitation consists of a lot of snow, ice and hail, with salt or sand, mass loss from Leading Edge (LE) will increase beyond this.

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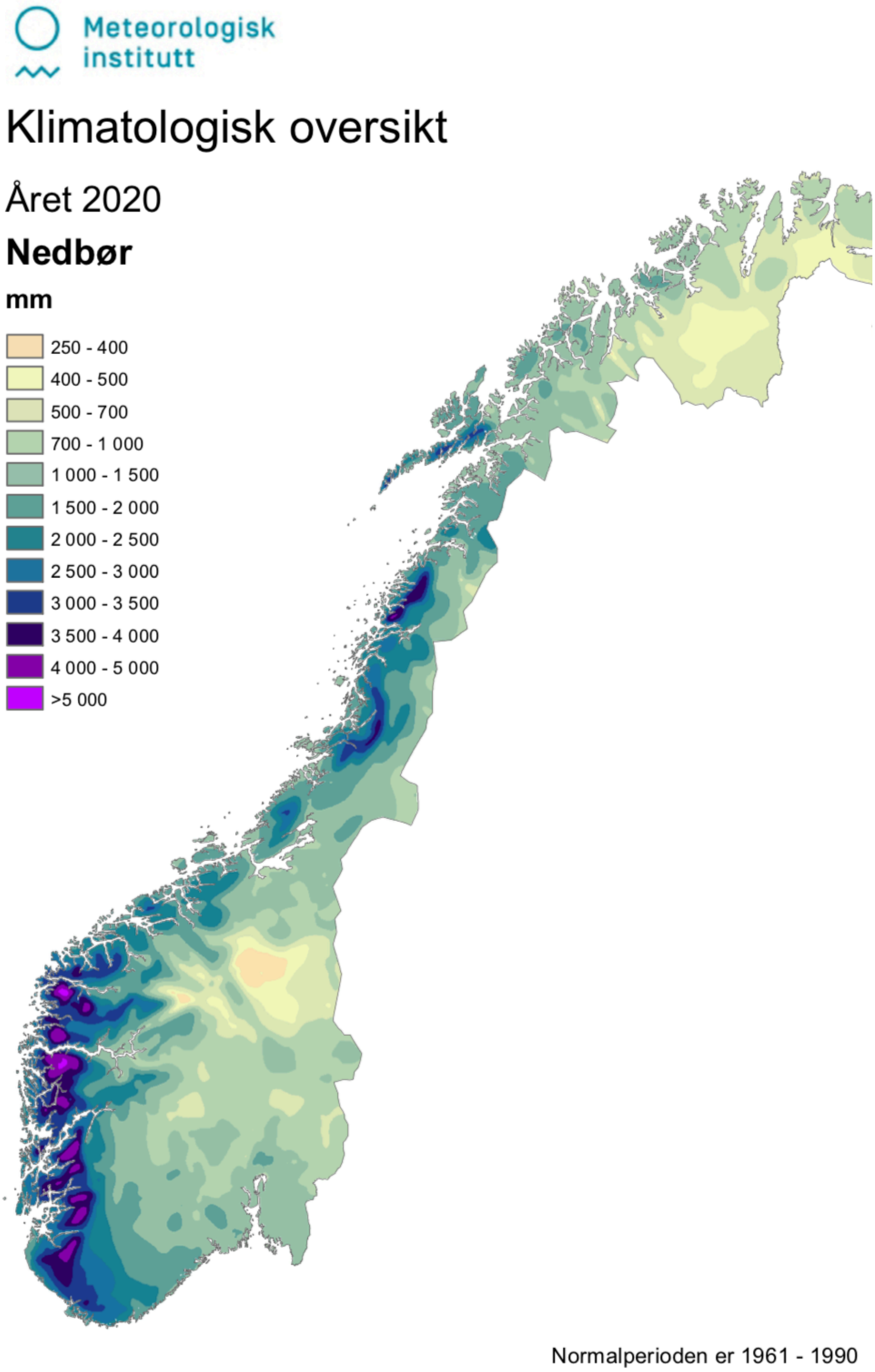
[6] https://link.springer.com/article/10.1007%2Fs40735-021-00472-0

Climatological overview (NORWAY) rain 2020 [7]



[7] https://www.met.no/publikasjoner/met-info

Through NORWEA, the wind industry states a total annual emission of max 150 grams pr. turbine[8].

That is a maximum of 60 kg for 400 turbines.

Our estimates show that emissions can be 41 000 % greater than the figures provided by NORWEA.

It is important to note that the wear on rotor blades is exponential.

Erosion Rate is exponential to Impact Speed or Impact Energy (see figure 4).

New and larger turbines will have far greater mass losses.

The average temperature in many places along the coast is below 4 degrees from November to April, which gives at least 5 months with the risk of icing and hail, in other words periods of higher average mechanical stress and emissions than those found in Scotland.

25 tonnes of annual emissions in the form of micro- and nanoplastics are thus sprinkled over outfields, pastures, soils, water sources and eventually fjords and sea areas.

How much of this will be Bisphenol A is uncertain, **but 1 kilo of bisphenol A is enough to pollute 10 billion litres of water. That's 10 000 000 000 litres.**

Since 2017, the WHO has advised that drinking water should have a maximum of 0.1 micrograms of BPA pr. litre. This is 0.000 000 1 grams per litre of water[9].

The environmental protection authorities in Norway have statistics on emissions of free Bisphenol A. These statistics are given in grams with emissions. Emissions from the wind industry are not included, and no decision has been made as to whether emissions from the wind industry can be broken down into harmful substances.

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[8] https://norwea.no/norwea-mener/2021/3/26/faktaark-vindkraft-plast-og-bisfenol-a
[9] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020L2184&from=EN

Introduction

Some reports say the coating is polyurethane while "*On the Material, Characterization of wind turbine-B_2017*" says that the cover layer on the Leading edge is also a specially developed epoxy "*developed for Leading Edge Protection*" (LEP)[10]. The same report also explains the mechanisms surrounding damage caused by raindrops, defined as the Water Hammer pressure effect.

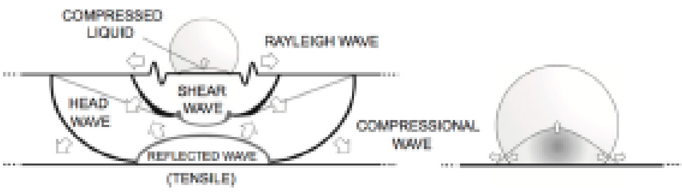

Figure 1 source: On the Material, Characterisation of wind turbine-B_2017

The fact that all objects that move quickly through air, hail and rain wear has been a known problem in the aviation industry since 1940, also in other industries there is a well-known problem with wear caused by flow.

The wind power industry has chosen to neglect and under communicate this in much the same way as the tobacco and sugar industry dealt with health effects.

That there is a wear problem today and that there will be a significantly bigger problem with larger turbines in the future, is confirmed by "*On the Material, Characterization of wind turbine-B_2017*" [11], which says: *Rain erosion protection coatings have been proposed, tested and validated with particular industrial solutions, but the proposed solutions are still not as reliable as the wind energy industry requires. Rain erosion has thus become a scientific challenge for the wind industry since there are no well-defined methodologies to design coatings against rain erosion and it is unclear how to modify their properties depending on the location, weather conditions, etc.*

What we know about the forces and mechanical stresses on wind turbines is that the stresses increase exponentially as the turbines become larger. Offshore wind turbines will wear 40-50% more due to salinity. Offshore wind is more unprofitable than land-based, and it thus requires much larger turbines, which in turn will result in much larger emissions.

Longer rotor blades, give increased speed in the blade tip. The industry is well aware of increased mass loss and thus increased emissions when they increase blade speed, but they believe increased blade wear can be

[10] That there is no bisphenol in the coating is undocumented information in the form of claims from the wind industry, they do not say anything about the coating. But also polyurethane has its environmental challenges with increased cancer risk and allergenic properties.
[11] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5666952/

justified by requiring less investment, e.g. that it requires lower investment costs, i.e. smaller and cheaper gearboxes.

The purpose of the report from Strathclyde is to predict the need for maintenance, but it also quantifies the mass loss in rotor blades. The report from Strathclyde focuses on a test of mass loss on a material sample. The selected measurement for erosion is mass loss as a percentage of the original sample. The ideal loss data would be the mass loss connected with area. Then the mass loss calculations would be easier to predict. But no body publishes data like this, therefore the Strathclyde report is the best available source.

The mass of the test material was measured before the experiment and after each exposure time. This will result in a direct numerical relationship between average monthly rainfall and erosion as a mass loss.

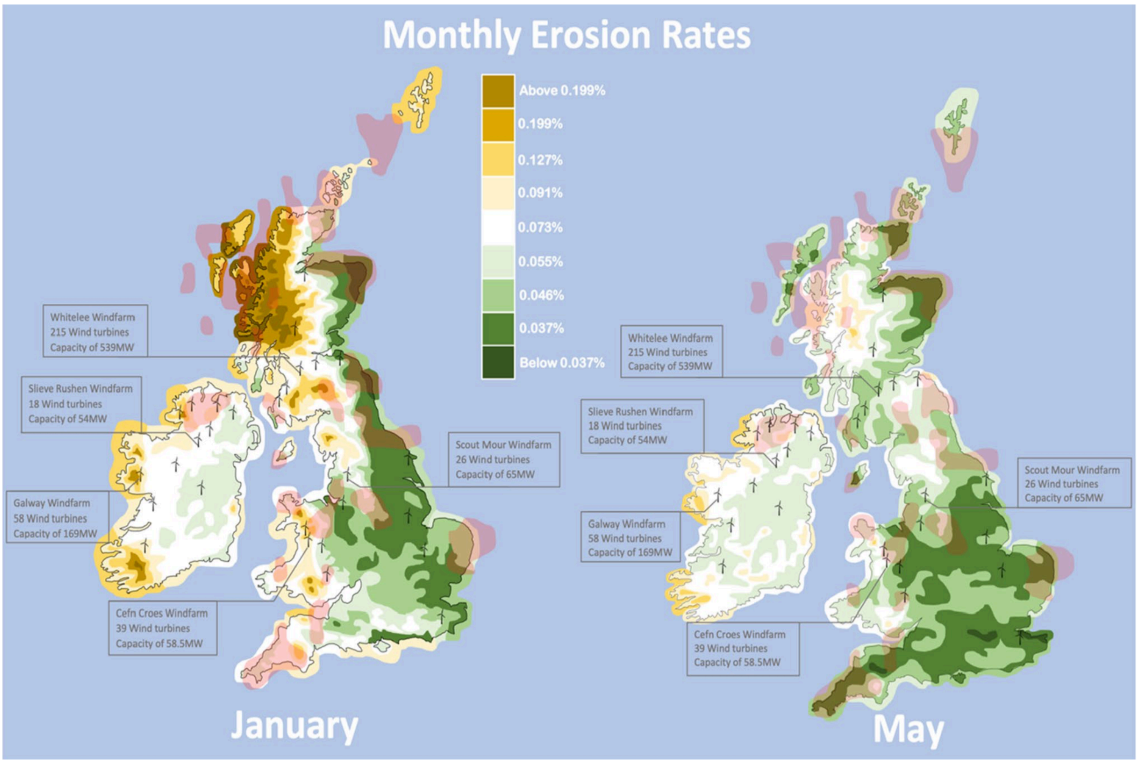

Figure 1. The monthly erosion rates in January and May with overlays of major wind turbine farms and areas of frequent hail. Source: Journal of Bio- and Tribo-Corrosion · March 2021)

The pulp loss mainly consists of two-component epoxy. A turbine wing is largely made of fiberglass reinforced epoxy where epoxy makes up approx. 40% of the pulp and fiberglass make up 60%. In addition, some balsa wood, divinycell (a kind of hard foam) and some other materials are used to create the profile for the wing construction.

Epoxy contains 33% bisphenol A. This amounts to approx. 13 - 15% of the total weight of a rotor blade. In other words, there is a lot of microplastic, **and a large part of this is bisphenol A.**

In this document, we do not consider the state of the emissions of microplastics, or the distribution of inert and harmful substances in the form of free chemicals. To differentiate this is an isolated large scientific work that should be carried out as it is known that all substances are broken down to a greater or lesser degree.

Pollution authorities throughout Europe should jointly launch a major impact assessment. Since we are talking about large emissions from turbine plants, one should also look at how epoxy is broken down in the animals' digestive system with mechanical processing, heat and acid.

> "*Bisphenols are not covalently bound to the polymeric structure, from which with time, or due to physical and / or chemical factors such as heat and acidity, can be gradually released into the external environment, contaminating water, soil and sediments, and later the rest of the agro-food chain*."[12]

The special thing about emissions from land-based wind turbines in Norway is that they are located higher than water sources and biotopes, and that they will be able to spread the problem over relatively large areas such as outfields and pastures. **In addition, many of these discharges could end up in drinking water sources.**

Loss of bisphenol will apply to those areas of the blade that are not covered by surface treatment, i.e damaged areas, and whether epoxy is used in the surface treatment. Where polyurethane cover layers are used, bisphenol will probably not be released until the cover layer has worn away[13], but the mass losses are microplastic and it will enter the food chain. Polyurethane contains isocyanates which are known to be both carcinogenic and allergenic.

The bisphenol A (BPA) content of the emissions will increase throughout the period of use and after use, as the materials are uncovered and exposed. In particular, current practice of burying rotor blades in landfills will result in high emissions over a long period of time.

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[12] Review article, Environmental Research 151 (2016) Monica Giulivo a,n, Miren Lopez de Alda b,n, Ettore Capri a, Damià Barceló b,c

[13] That there is no bisphenol in the coating is undocumented information in the form of claims from the wind industry, they do not say anything about the coating but also polyurethane has its environmental challenges with increased cancer risk and allergenic properties.

The experiments performed at the University of Strathclyde in short

The Strathclyde report only looks at rain (no ice, snow or hail), but describes that previous studies show that hail causes both surface damage and micro delamination that results in accelerated and large mass losses due to rain.

Weather data are taken from Ireland and Scotland. Data are collected in January and May, which are the wettest and driest months, respectively.

The test specimens are exposed to a similar load as the average weather for a 20-year period from the weather data.

The speed in the test was 60 m/s, which corresponds to the speed at the end of a 50-meter wing. In other words, the test is relevant for large parts of the turbine blades. The rotor speed increases exponentially beyond the blade wing. For example. turbines with a diameter of 140 meters on the wings have a speed of approx. 80-100 m/s at the tip. The inner part of a turbine blade will wear considerably less than the tip.

The experiment was also repeated with salt water with a view to offshore wind turbines. Salinity was 3.5%, which is equivalent to seawater in the UK and Ireland. The mass loss then increases by 40-50%.

Mass loss also results in increased turbulence and drag, which results in lost efficiency. To counteract lost production, the blade angle is changed, which exposes a larger surface to mechanical wear, which in turn results in increased mass loss.

The University of Strathclyde writes that they have used the same material as on wind turbine blades, but which is not further described, e.g. about which surface treatment has been used in the experiments. It can mean that the figures only apply to open exposed epoxy without surface treatment, even though the text indicates that complete sheets of coating have been used in the experiments. The authors have been contacted but we have not been contacted at the time of writing.

The report says the following about the wear:

> "*The degradation of the sample should erode in three distinct stages. The first is the initiation period; where the sample is at its smoothest and difficult to penetrate, this is when the turbine blades are brand new and operating at optimal efficiency.*
>
> *Secondly is steady state erosion; where the sample has been impacted by a critical number of droplets to affect the surface roughness of the sample enough to instigate more considerable erosion which continues at a constant rate. It is during this stage that the turbine starts to decline in efficiency.*
>
> *Lastly the third stage is the final erosion region where the erosion rate decreases, however, this is when the turbine blade is at its most vulnerable and the erosion on the blades can begin to become structural weak points.*"

From other reports

Another report "*Sustainable_End-of-Life_Management_of_Wind_Turbine*"[14] acknowledges the problem: "*For erosion protection, a load reducing strategy can be realized as so-called erosion safe control, i.e., reduction of tip speed during heavy rain."* (page 4).

Report Accelerated rain erosion of wind turbine from DTU[15]: "*The liquid coating materials contain the same basic compositional components: resin, solvents, pigments and additives*." (page 9).

We have looked at a number of reports and all conclude that erosion due to rain is a major problem. The reports focus mainly on operation and maintenance, not on emissions and environmental damage.

With the increasing size of the turbines, which gives high speed to the blades, it appears that edge tape and similar do not meet goals. Modern and large wind turbines therefore use a layer of polyurethane-based paint/varnish on top of the epoxy gelcoat or epoxy coating as protection.

In addition to Leading Edge Erotion (LEE), several research sources mention pitting and delamination as known problems.

Other comments

There are examples from both the UK and Denmark that after 5 years you either have to make very large critical, costly repairs such as at London Array Park or demolition/replacement and Anholt in Denmark. Both locations with a blade diameter of 120 meters.

The average temperature in many places on the Norwegian coast is below 4 degrees from November to April. This means minimum 5 months with danger of icing and hail. In parts (like Troms and Finnmark) there are more extreme weather conditions. Norway will have higher average mechanical load and emissions than those found in Denmark, England and Scotland.

Leading Edge Erosion (LEE) causes an annual production loss of somewhere between 56 and 75 million euros. A large industry has emerged around the maintenance of rotor blades. That this industry can live off the alleged emissions/mass loss of 0-50 grams (max 150 grams per turbine) is a logical shortcoming which at best appears naive. But our environmental authorities accept this as the truth. For Norway (with 1164 turbines) the total annual maintenance would be max 174 kg.

The maintenance costs for a 500 MW offshore wind turbine plant will be between 2 and 8 million pounds per. year. A quick calculation indicates that it can be up to £80,000 per turbine.

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[14] https://pubmed.ncbi.nlm.nih.gov/33673684/
[15] https://backend.orbit.dtu.dk/ws/portalfiles/portal/116954840/Shizhong_Zhang_978_87_93054_49_3_fil_fra_trykkeri.pdf

The same source tells that repairs and production losses cause lifetime costs of 1.3 million pounds[16].

This confirms that the industry calculates large emissions from wear from rotor blades.

Several reports show that the maximum speed for today's large turbines is just below 100 m/s, while larger turbines will have speeds up to 110 m/s. The speed cannot increase indefinitely as the flow speed becomes unfavourably high and the efficiency will decrease.

The choice of turbine type in many places confirms that large loads are expected on both the rotor blades and the construction itself.

Wear and emissions can be divided into three phases:

Phase 1 - wear on polyurethane coatings, the Leading-edge protection (LEP), which is not as environmentally critical but it releases microplastics that contain isocyanates and other substances that are carcinogenic and allergenic. Some turbines have epoxy as (LEP) instead of polyurethane.

Phase 2 - wear on Gelcoat- which is an epoxy. This gives emissions but not major mechanical weakening on the turbine blade.

Phase 3 - wear into the glass epoxy layer under the gelcoat. This results in increasing emissions and structural problems on the turbine blades.

Results and conclusion

Disclaimer: The University of Strathclyde report says too little about test criteria and our estimates must therefore be regarded as qualified estimates. Nevertheless, they provide grounds for assuming that there may be a significant problem that clearly needs to be highlighted and taken very seriously. In our estimates we use the results from the University of Strathclyde report.

We have in this report carried out estimates for climate along the Norwegian coast. We have calculated mass loss on the leading edge (LE) from 50 meters and beyond on the blade. The estimates show that there are almost certainly large and strongly under communicated emissions from the wind turbine industry. Increased blade diameter gives increased tip speed. With speeds more than 300 km/h = 83 m/s, the encounter with raindrops, hail and ice particles will increase the erosion of the blades.

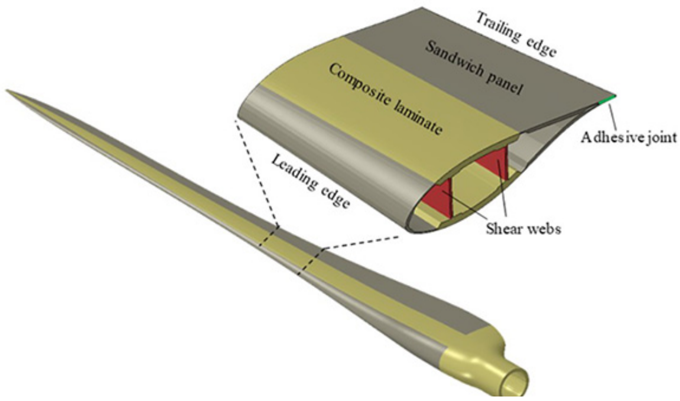


Figure 3 Typical wing profile

Source: https://www.dtu.dk/english/news/Nyhed?id={CDC59567-A8A1-4ACE-866A-7FD8D559D5FF}

[16] https://www.sciencedirect.com/science/article/pii/S1364032119305908

In our estimate, we have used a Vestas 136 turbine, with a diameter of 136 meters and a total blade weight of approx. 60 tons. We have used 700 kg as exposed Leading edge per turbine. That is little more than 1% of the total blade weight.

After we published our first edition of this report Kieran Pugh, PhD University of Strathclyde, wrote this in an email dialogue with us "*The affected area which the experiments were conducted, which was at the tip on the leading edge, will weigh 50kg max. This is due to the tip only traveling at the speed tested. This is the upper estimate of the combined three blades*".

In our estimate, we have used 12 kg as weight on LE on the last meter of the blade (the tip). It gives 36 kg for all three blades. It is approx. 40% less than the weight Kieran Pugh states as maximum weight.

Kieran Pugh also states that based on 50 kg the erosion is 0.5735 kg per turbine per year. He specified "*This is also a worst-case scenario involving assumptions like the turbine is operating at maximum operational speed at all times during rain, this means this estimate of mass loss is at the most extreme case and is unlikely to increase.".*

With our formula we get an annual erosion of 0.220 kg with 36 kg LE and 60 m/s. It seems that our estimates are very cautious compared to what Kieran Pugh himself has as erosion at 60 m/s.

In the beginning (phase 1) our estimated emission figures will be set too high, but when there is visible wear and tear, our figures will probably be low (see phases 1, 2 and 3).

When the wear has reached a certain point, it will begin to break down into larger particles and the emissions will accelerate.

We have reviewed a number of reports on maintenance and it is clear that a turbine blade cannot survive 15-20 years in exposed environments without significant maintenance.

Previously, suppliers of maintenance services showed and discussed the jobs together with figures and documentation. In 2021, almost all information will be kept hidden and it is very difficult to find available figures and data. This can be regarded as a confirmation that the emissions are high.

It is worth noting that weight, volume and consequently the emission figures will increase in the 3rd power as a result of increasing size of turbines and salinity in the air will increase this problem by another 40%.

The experiments at Strathclyde show that a rainfall with pure particle-free fresh water of 50 mm per month. results in a mass loss of 0.037% per mnd. and that a rainfall of 500 mm per. mnd. gives a mass loss of 0.199% per. mnd. The wear with seawater (3.5% salinity) is 40% greater.

Many places on the Norwegian coast have annual rainfall of approx. 2,500 millimeters.

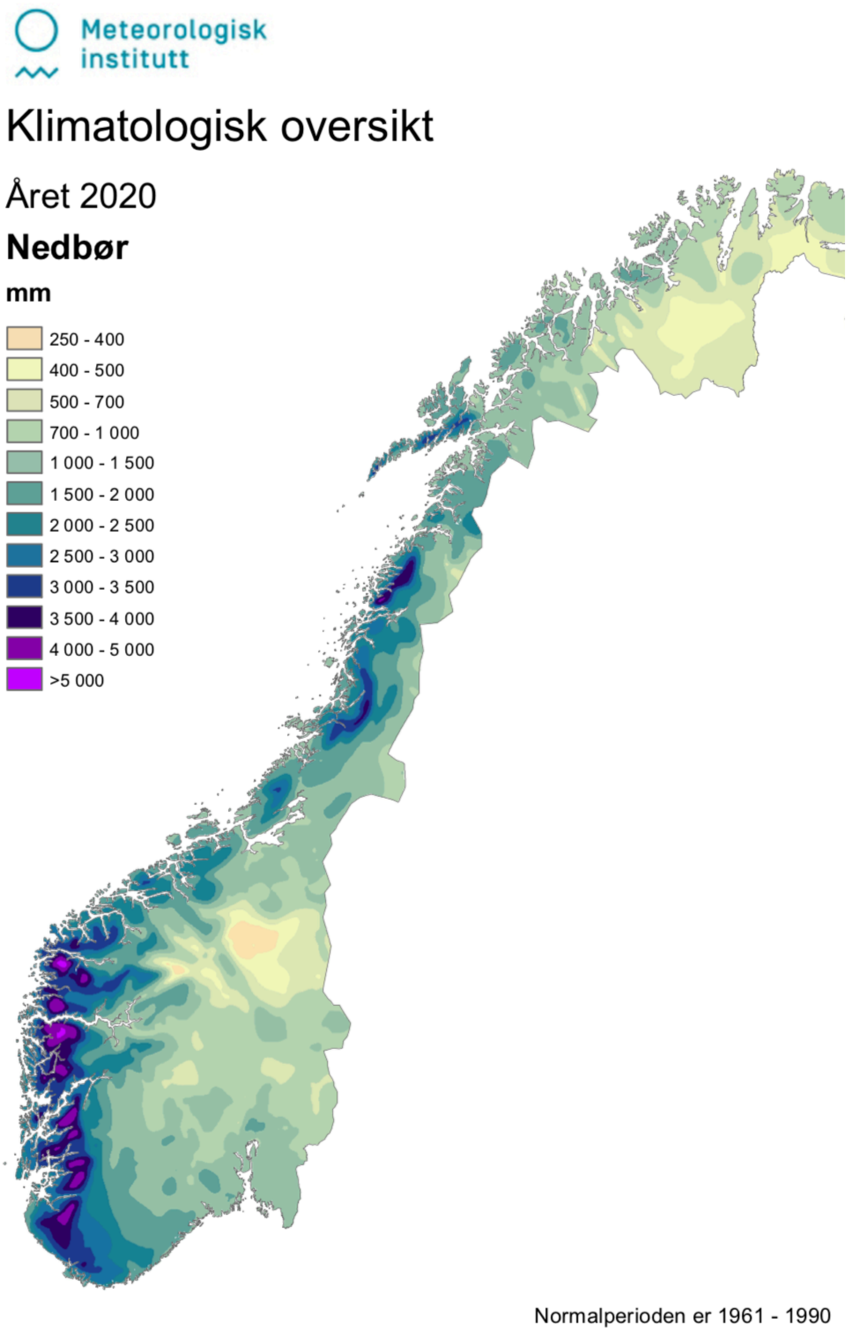
This gives us this formula for wear and tear: f(x) = $0{,}972\ \% * (\frac{diameter}{100})^{11{,}4}$

We use an estimate of 700 kg as weight on the exposed leading edge. This will give an annual loss of 62 kg per year per turbine.

20 turbines are likely to produce emissions greater than 1.2 t per year and 31 t over 25 years.

We only count the annual rainfall as rain. If there is a season with a lot of ice and hail, the mass losses will increase beyond this.

Climatological overview (NORWAY) rain 2020 [17]



[17] https://www.met.no/publikasjoner/met-info

Conclusion

The report from Strathclyde mentions that hail and harsh weather conditions will increase wear and tear.

Based on the Strathclyde report it is unlikely that erosion with Norwegian winter conditions will be as low as for Scotland and Ireland. 62 kg annual erosion of micro- and nanoplastics is therefore probably a cautious estimate per. turbine.

In Norway, according to NVE, there are close to 400 turbines with a wing diameter of 130 meters or more. An estimate is then that the total emissions from these 400 turbines are approx. 25 tonnes a year.

In the course of 25 years, it amounts to an estimated 620 tonnes!

Through NORWEA, the industry states a total annual emission of a maximum of 150 grams per turbine[18].

This corresponds to a maximum of 60 kg for 400 turbines.

Our estimates show that the emissions can be over 41 000 % greater than what NORWEA states.

Note that the erosion is exponential.

Larger turbines with higher tip speed will have much more erosion.

Erosion Rate is exponential to Impact Speed or Impact Energy (see graph)

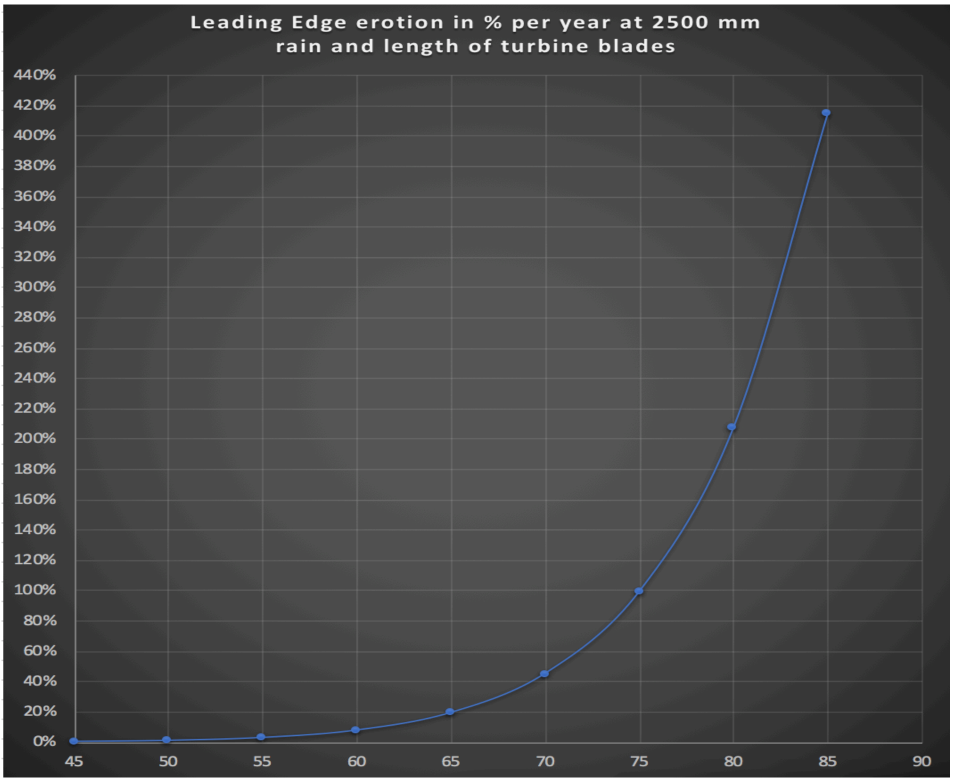


Figure 4. erosion (loss in percent) as a function of precipitation, speed and length of turbine blades

[18] https://norwea.no/norwea-mener/2021/3/26/faktaark-vindkraft-plast-og-bisfenol-a

The average temperature in many places on the Norwegian coast is below 4 degrees from November to April. This gives the risk of at least 5 months with of icing and hail and long periods of higher average mechanical stress and emissions than those found in Scotland.

25 tonnes of annual emissions in the form of micro- and nanoplastics, which are sprinkled over outfields, pastures, water sources and eventually sea areas.

How much of this will be epoxy made with Bisphenol A (BPA) is uncertain, but 1 kilo of BPA is enough to pollute 10 billion litres of water. That's 10,000,000,000 litres.

Since 2017, the WHO has advised that drinking water should have a maximum of 0.1 micrograms of BPA per litre. That is the same as 0.0000001 grams per litre of water[19].

Food producers, dairy farms, reindeer slaughterhouse and Norwegian sheep farmers market pure milk and pure meat from Norwegian mountains. Fish and seafood is a major export industry. With large emissions of toxic compounds from the wind turbine industry, this industry will be exposed. Wind turbines can have major ecological, health and economic consequences.

We do not know any wind turbine facilities having applied for or received emission permit.

Figure 5 Photo: A small blade profile - to get an impression of proportions. Own photo, from testing

[19] https://www.nmf.no/wp-content/uploads/2021/02/Green-Warriors-of-Norway-ECHA_REACH-Bisphenol-comments-and-evidence.pdf

Guleslettene wind power plant (Florø in Norway) – an example

Guleslettene which has been in focus due to conflict with the municipal waterworks, has approx. 3575 mm rain per. year. They have Vestas 136 turbines with a diameter of 136 m on the wingspan.

The formula for calculating wear then becomes $f(x) = 1{,}4\ \% * (\frac{diameter}{100})^{11{,}4}$.

It gives an estimate of 90 kg of emissions of micro- and nanoplastics per turbine and 3,960 kg annual emissions.

Over 25 years the emissions will be 99 tonnes.

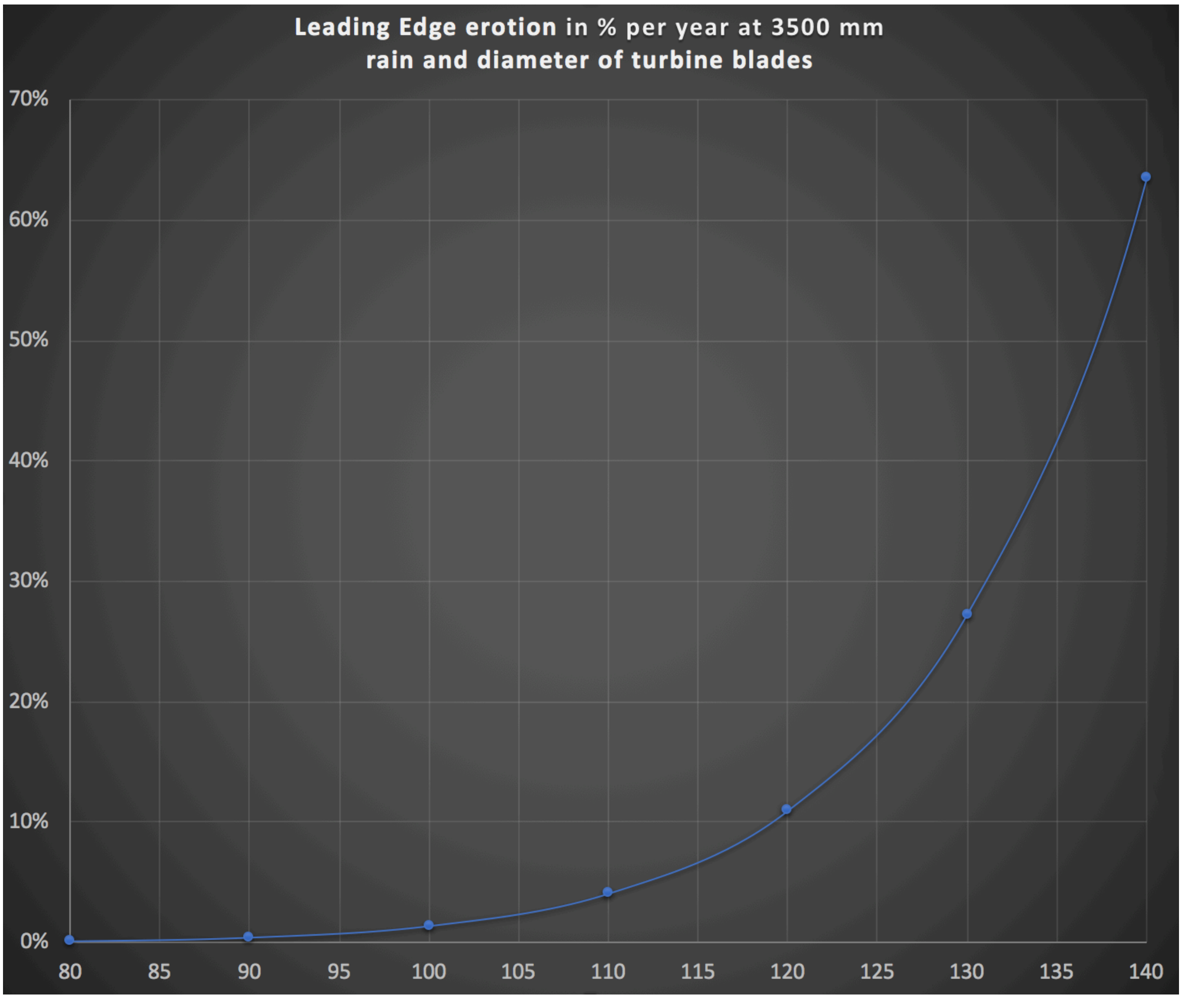


Figure 6. erosion (loss in percent) as a function of precipitation, speed and length of turbine wing

Logical check

In the absence of good published documentation that quantifies mass losses, we have found this one report from Strathclyde.

In the report, *The increasing importance of leading-edge erosion and a review of existing protection solutions from 2019*[20], it appears that there are large and known problems with mass loss and that they will increase with offshore wind:

> "*Blade leading edge erosion has become an important issue for the offshore wind industry*." and it goes on *"… greater blade lengths and higher tip speeds, as well as a move to new markets with monsoonal climates, has caused leading edge erosion to progress from an issue that only affects a small number of turbines in the most extreme environments to a major problem that effects entire wind farms*." It also states *"..As a result, blades can experience significant erosion within just a few years, which considering their supposed 25-year service life, is a serious problem.*"

You can also read about accelerated tests performed at 135 m/s where LEP is worn through in 30 minutes. When we know that offshore turbines get up to 110 m/s, the emissions from offshore wind must be large.

Here is a short quote about Bisphenol A from a blog within the construction industry. The author has many years of experience with environmental classification and is affiliated with Statsbygg. She can´t find any good explanations for whether epoxy contains Bisphenol A or not, nor how much. The author writes that she received the following answer from the Norwegian Environment Agency:

> "*Bisphenol A and Epichlorohydrin = epoxy resin are not currently on the priority list, but it is harmonized classified (a substance that has been adopted in the EU / EEA and included in Annex VI of CLP), among others. a with environmental hazard classification H411 «Toxic, with long-term effect on life in water*"[21].

The Norwegian Environment Agency therefore recommends, based on both the environmental hazard classification and the suspicion that it has endocrine disrupting effects, that it is a good "precautionary principle" that one tries to find other and more environmentally friendly alternatives.

Remember that Bisphenol A amounts to approx. 13 - 15% of casting weight of a turbine blade.

When it comes to wind turbines and the environment, no rules or guidelines have been made that safeguard people's health, pollution and the environment[22].

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[20] https://doi.org/10.1016/j.rser.2019.109382
[21] https://www.futurebuilt.no/Blogg#!/Blogg/Inneholder-epoxy-stoff-paa-prioritetslisten-Eller-ikke
[22] https://www.futurebuilt.no/Blogg#!/Blogg/Inneholder-epoxy-stoff-paa-prioritetslisten-Eller-ikke

Dismantling and demolition

In Norway there are no requirements or guidelines for either disassembly or handling turbine blades after the end of use. The only thing that exists is a requirement that after 12 years of operation, money must be set aside for demolition. That money is set aside presupposes that there is money in the operating company, legally it is the landowner who is responsible for clean-up.

The practice of demolition has been so-called controlled rollover into terrain, it pollutes the terrain a lot and it makes much of what is described as circular economy impossible, especially when it comes to all fiberglass and epoxy. The only reason to roll over in terrain is that it costs approximately only approx. 33% compared to disassembly.

Rotor blades pollute during operation and are an environmental problem after the operation phase, there are no requirements for how this composite waste is to be handled.

When it comes to alternative use, there are currently few or no good methods.

The wind turbine industry has previously dumped some of the waste in Africa through so-called second-hand sales, today most of it is buried all over the world. Often the turbines will remain standing after the end of the operational phase, there is a real danger in Norway as well.

Figure 7 Photo: Bending test of a section on a wing profile. Own photo, from testing

"You can´t escape physics and knowledge, no matter how good you are at rhetoric"

"THE TURBINE GROUP" JULY 2021

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