From: [redacted]
To: IPCN Submissions Mailbox
Subject: Fwd: Microplastics & BPA
Date: Wednesday, 4 June 2025 6:44:52 PM
Attachments: A0010_EnvironmentandCommunications_2023-24SupplementaryBudgetestimates_ClimateChange,Energy,theEnvironmentandWater (1).pdf
0043 Mr Ian McDonald submission - inquiry into PFAS contamination in waterways NSW Dec 2024.pdf
Bisphenol-A-Pollution-Wind-Turbines.pdf
energies-17-06260-with-cover.pdf
Green-Warriors-of-Norway-ECHA_REACH-Bisphenol-comments-and-evidence.pdf

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Hi Commissioners, here is some more information regarding Blade shedding.

Rgs,
Ross Johns
Wimmera Mallee Enviromental and Agricultural Protection Association

Sent from my iPad

Begin forwarded message:

From: [redacted]
Date: 4 June 2025 at 4:45:08 pm AEST
To: Ross Johns [redacted]
Subject: Microplastics & BPA
Reply-To: [redacted]

Hi Ross,

Here is some information I have pulled together - cut and past what you need.

It should not be on the objectors to supply scientific evidence surely, but for the proponents to commit, baseline and prove during the life of the project that they are not polluting.

There is absolutely evidence that they do pollute - to what extent is debated and downplayed by the wind industry of course. Very small amounts of BPA are required to cause pollution. EPA is not paying attention to this - I have heard other people say this.

Safety should be demonstrated and practiced not just modelled. Human health impacts should be protected by the precautionary approach.

Hope there is something of use here. I have put a call out and will send anything else that comes through. There are a few attachments.

Microplastics and BPA pollution is known across the world from Wind Turbine blade erosion.

The Australian Department of Climate Change, Energy, the Environment and Water (DCCEEW) lists BPA as a chemical of concern in plastics, highlighting its use in polycarbonate plastics and epoxy resins, including in wind turbine blade coatings. However, no specific regulatory limits for BPA emissions from industrial sources like wind turbines are outlined, as the focus is primarily on water quality and food contact materials.

https://www.dcceew.gov.au/environment/protection/chemicals-management/chemicals-of-concern-plastics

In essence, the Australian EPAs' duty of care for public health is a comprehensive one, rooted in the principle of preventing and minimizing harm from environmental pollution and waste, and enforced through a combination of regulation, monitoring, incident response, and legal powers at state levels. The EPA must put the oneous on developers to prove they will and subsequently do not pollute BPA and microplastics during the life of energy projects by useing third party companies to monitoring for this pollution and make the data publicly available.

Energy projects (coal) are required to monitor pollution, similarly other energy projects should provide publicly available data to meet the community expectations around pollution. Measuring BPA pollution throughout the life of projects through third party visual inspections of blades, soil and water tests. Baseline testing for BPA and microplastics should be done prior to construction.
https://www.epa.nsw.gov.au/Working-together/Community-engagement/Regulation-of-power-stations/Licence-reviews

BPA and microplastics are a concern which are repeatedly raised by communities in their submissions to planning committees and in response to planning applications that proposed to host wind and solar projects in Australia.

- Is the EPA monitoring pollution from turbines onshore in Australia?
- If not what is the reason for not doing this at existing energy projects?
- What is the reason for not taking a precautionary approach to human, animal and environmental health.
- The wind industry should not be held as the credible source of information; the fox shouldn't be left to guard the hen house.
- Our concern is the problem is known, but the studies are not conducted. Permits must include mandatory studies.
- Independent studies should be completed at existing projects, such as late life wind farms to assess for the presence of BPA
- Farmers in the vicinity of wind projects are rightly concerned with their ability to produce clean food as required by various Australian Standards, notably the Livestock Producers Association and quality audits do require declaration of infrastructure which grazing animals come into contact. It is a requirement that animals be excluded from areas of potential contamination.
- Large scale renewable energy projects must be required under planning permit to demonstrate they are not causing harm and we request such monitoring to be mandated.
- Blade erosion and delamination is a known problem, yet proponents downplay this environmental risk with responses that are similar to this reponse in the Chalumbin Wind Farm PER.
  "BPA is a building block chemical found in epoxy resins used in producing the blades, with BPA not being present in the surface coatings/Leading Edge Protection. They are in hardened/cured stage (inert) for a finished blade in service life, as such are not to be exposed to the environment and would not be able to leach off the blade and into the environment. Wind turbine manufacturers are progressing technology to continually improve recyclability of wind turbine components; this includes processes that will eliminate the need for landfill disposal of epoxy-based blades when they are decommissioned."

"While the EPA does not explicitly monitor BPA at renewable energy sites, general environmental assessments for such projects may include monitoring for pollutants if deemed necessary under state-specific regulations or project-specific Environmental Impact Assessments (EIAs). For instance, large renewable energy projects require EIAs under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), which could involve assessing potential chemical pollution, including microplastics or BPA, if identified as a risk. However, this is not routine and depends on the project's scale and location, particularly for offshore wind farms where marine pollution is a concern.

Australian planning department submissions related to wind farms occasionally address BPA as part of broader concerns about microplastic pollution from turbine blade erosion. Key examples include the Chalumbin Wind Farm response, which estimates low BPA emissions, and submissions to NSW and SA inquiries highlighting higher estimates (e.g., 60 kg microplastics per turbine annually), though these lack robust evidence. Community submissions, as seen in social media posts, also reflect BPA concerns, but official planning documents rarely prioritize BPA monitoring. The EPBC Act and state planning frameworks allow for such issues to be raised, but no standardized requirement exists for BPA-specific monitoring in wind farm approvals.

https://www.windconcerns.com/toxic-blade-time-bomb/#identifier_4_4880
Good information here - and links to reports.12 minute video about it.
Solberg report also references their reports.

[Scotland Littered By Tonnes of Toxic Plastics Shed By Thousands of Wind Turbine Blades]

Scotland Littered By Tonnes of Toxic Plastics Shed By Thousands of Wind …

For a taste of your wind 'powered' future, look no further than the Scottish Highlands – where some 4,500 of the…

Question on notice no. 10

Portfolio question number: SQ23-001636

2023-24 Supplementary Budget estimates

Environment and Communications Committee, Climate Change, Energy, the Environment and Water Portfolio

Senator Gerard Rennick: asked the Department of Climate Change, Energy, the Environment and Water on 23 October 2023—

Senator RENNICK: ... I've asked a question about bisphenol A in wind turbines. Is there epoxy resin in wind turbines blades-yes or no?
Mr Fredericks: I'm pretty sure there's no-one at this table that can answer that question. I have a sneaking suspicion we will probably need to take that on notice.
Senator RENNICK: Okay. I was told in a former answer that it wasn't used, but my understanding of it is that bisphenol A is used in the epoxy resin that goes on wind turbines. It's an essential ingredient of the resins that is used on wind turbines. If that breaks down, which it does over time, and if that gets into the water, especially for offshore wind turbines, that can damage our marine life, which wouldn't be good, would it?
Mr Fredericks: Fair enough. That's an important question. I want to answer that well for you, so we'll take that on notice.
Answer —
Please see attached answer.

Question No: SQ23-001636

Hearing: Supplementary Budget Estimates

Outcome: Outcome 2

Division/Agency: Electricity Division

Topic: Bisphenol A used in epoxy resin

Hansard Page: 20

Question Date: 23 October 2023

Question Type: Spoken

Senator Rennick asked:

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Mr Fredericks: Fair enough. That's an important question. I want to answer that well for you, so we'll take that on notice.

Answer:

1. The responses previously provided to the Supplementary Budget Estimates written question of 23 February 2023 and Budget Estimates written question of 9 June 2023 are correct. That is:
    a. epoxy resins are used to manufacture wind turbine blades; and
    b. there is no evidence in Australia or internationally that erosion of epoxy resins from wind turbines leads to significant Bisphenol A (BPA) emissions.
2. BPA is used to make epoxy resins which are then used to manufacture wind turbine blades. BPA is chemically transformed in the process of making the epoxy resin and is irreversibly bound into the matrix of the epoxy in the turbine blades. This means it cannot leach or wash out of the turbine blades.

Submission No 43

INQUIRY INTO INQUIRY INTO PFAS CONTAMINATION IN WATERWAYS AND DRINKING WATER SUPPLIES THROUGHOUT NEW SOUTH WALES

Name: Mr Ian McDonald

Date Received: 10 December 2024

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10 December 2024

Select Committee on PFAS Contamination in Waterways and Drinking Water Supplies Throughout New South Wales

Dear Panel Chair and Commissioners,

Contamination from renewable energy componentry is an issue that is being swept under the carpet. It's time governments stopped putting renewable targets ahead of the nation's public health and food security.

The long-term problem of toxic contamination finding its way into soil profiles and waterways from wind/solar componentry and BESS is acknowledged worldwide as a '***ticking time-bomb'***.

Toxic PFAS, a '*Forever chemical'* imbedded in lithium-ion batteries presents a dangerous source of chemical pollution that recent research carried out by Dr Jennifer Guelfo of Texas Tech University and Dr Lee Ferguson of Duke University found in a peer reviewed co-authored paper published in various science journals July this year, threatens the environment and human health. They found alarming levels of the chemicals in the environment near battery manufacturing plants in the US, Belgium and France, and discovered that waste from batteries disposed of in landfills was developing as a major pollution source.

'Forever chemicals' are a class of man-made compounds most often used to make products resistant to water, stains and heat. They are called '*forever*

chemicals' because they do not naturally break down and have been found to accumulate in humans. The chemicals are linked to cancer, birth defects, liver disease, plummeting sperm counts and a range of other serious health problems.

The Guelfo/Ferguson paper notes that few end-of-life standards for battery waste exist, and the vast majority end up in landfills where it can leach into waterways and soil profiles. Detection of the chemicals in snow far from manufacturing plants or landfills suggest the chemicals easily move through the atmosphere.

The study noted previous research that as little as 5 per cent of lithium batteries are recycled. That could yield a projected 8 million tons of battery waste by 2040, if battery recycling is not dramatically scaled up with demand.

Another particularly toxic '*Forever chemical'* is Bisphenol A (BPA), recognized by the World Health Organisation (WHO) as an endocrine disrupter that has been linked to about 80 diseases including cancer and reproductive disorders and can be lethal for young children.

All epoxy resins contain BPA or similar bisphenol components. Epoxy resins are used in almost every part of our daily life (BPA *in a confined state*) such as paints, plastic drink bottles, flooring etc and in the manufacture of wind turbine blades. Epoxy resins are also used in the manufacture of wind turbine blades. The blades, however, wear and then shed a fine dust of BPA throughout their life. This dust is spread wide and far by wind and if only one gram of it gets into dam or town storage waters, 10million litres of water is polluted and then rendered unusable. This dust (BPA *in an unconfined state*) from eroding blades has already covered large areas of our planet in proximity to wind farms and BPA is leaching into soils and waterways. Furthermore, the process is accelerated when the blades are cut up, dumped (on-site) and buried.

The wind industry openly admit that any wind turbine will emit in excess of 60kg of microplastics containing '*forever chemicals'* per year into the atmosphere which will find their way into soil profiles and waterways. That is the equivalent of about 50 tonne of pure unadulterated BPA pollutants over 20 years finding their way into water catchments from a typical 100 turbine wind farm.

As an accredited LPA livestock producer selling beef into the Grass-Fed domestic and export markets, I am fully aware of the strict compliance requirements of the rules and regulations set down by Meat Standards Australia in regard to feed containing chemical residues within a Withholding Period when harvested, and any livestock still within a Withholding Period or Export Slaughter Interval (ESI) as set by SAFEMEAT following treatment with any veterinary drug or chemical, and their slaughter interval for export.

To meet these criteria a National Vendor Declaration (NVD) must accompany all livestock movements and there is an obligation that I must be absolutely satisfied that I have correctly completed all parts of the NVD and that I understand that any misleading or unverified statements may result in prosecution, heavy fines or loss of my LPA accreditation thereby precluding me from trading.

Australia's reputation for clean green '*food and fibre'* has been built over generations on the back of good practice and strict governance. A priceless reputation second to none and envied by our competitors. Export destinations like the US, Japan, Korea, China and Europe are very aware of the dangers of BPA in foods and packaging. If they were to get a whiff that our beef or lamb could be contaminated with heavy metals or other *'forever chemicals'* like PFAS, our brand, built over generations would be destroyed overnight.

International public health advocates are sounding alarm bells about the need to find alternatives to the toxic chemicals and heavy metals imbedded in renewable energy componentry. Accordingly, there needs to be a far greater focus on the toxic contamination risks arising from wind/solar farms and BESS potentially causing leaching of '*Forever chemicals'* and heavy metals such as cadmium, cobalt, lead, lithium-copper, mercury, and nickel into our agricultural land, water resources and atmosphere, and also a greater focus on the associated Occupational Health & Safety risks, the impact on Intergenerational Equity for our children and grandchildren and the potential elevated stock toxicity levels as a measure to protect crops, livestock and producers, thereby ensuring food security for future generations.

The energy transition has not been properly thought through and it has far too many *'unintended consequences'* for it to be fit for purpose as presently there is no satisfactory waste management plan for where the hundreds of millions of toxic solar panels, hundreds of thousands of poisonous wind turbine blades, and millions of tons of dangerous batteries will eventually end up.

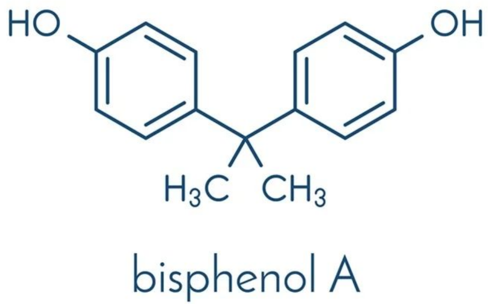
This nation cannot afford to let public health and food security be undermined by a hasty energy transition, and until such time as environmental, property, and food chain protection plans have been established, I call on the NSW government to apply the *'precautionary principle'* and initiate a moratorium on all wind/solar farm and BESS applications.

Ian McDonald, Grazier

Bisphenol A Pollution from Wind Turbines

Tim Smith 13/07/2023

What is Bisphenol A?



Bisphenol A (BPA) is a chemical produced in large quantities for use primarily in the production of polycarbonate plastics and epoxy resins.

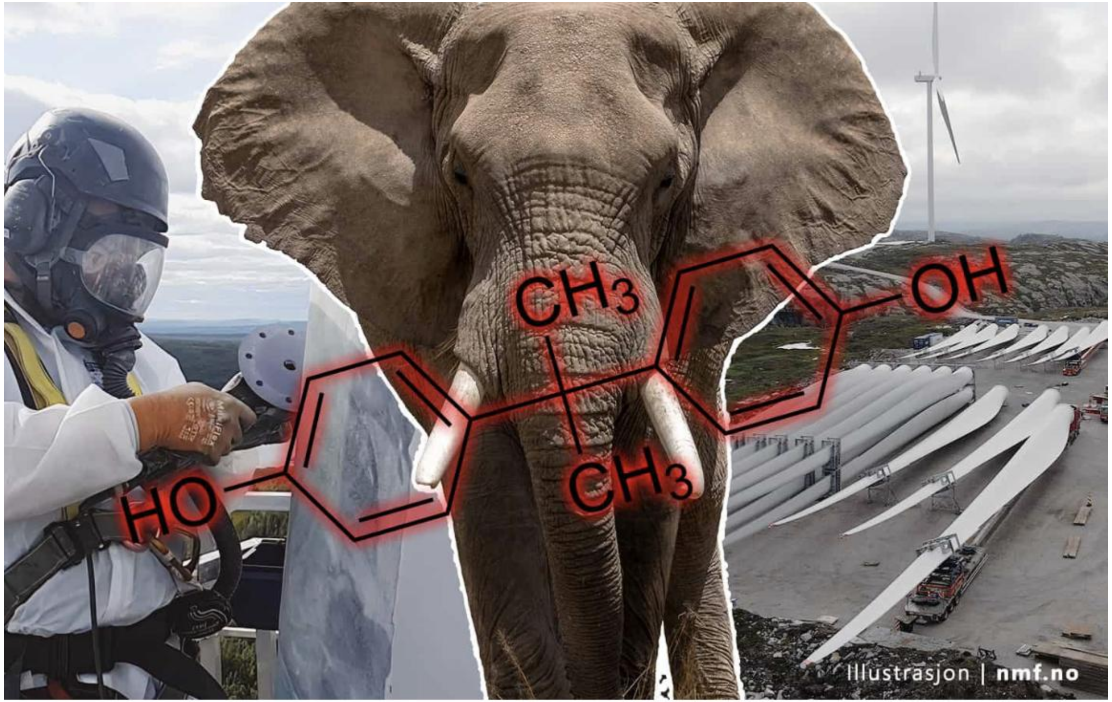
“Bisphenol A is the most toxic substance we know’

- Swedish Environmental Protection Agency

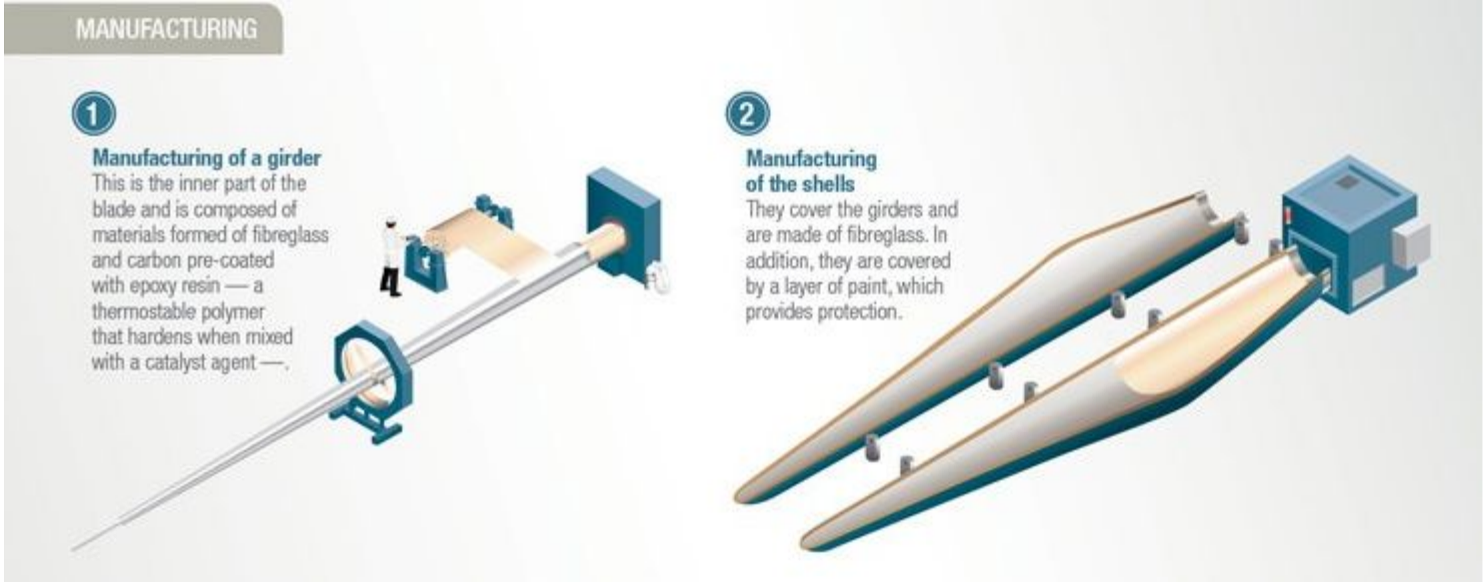
New Regulations

Avoid release to the environment!

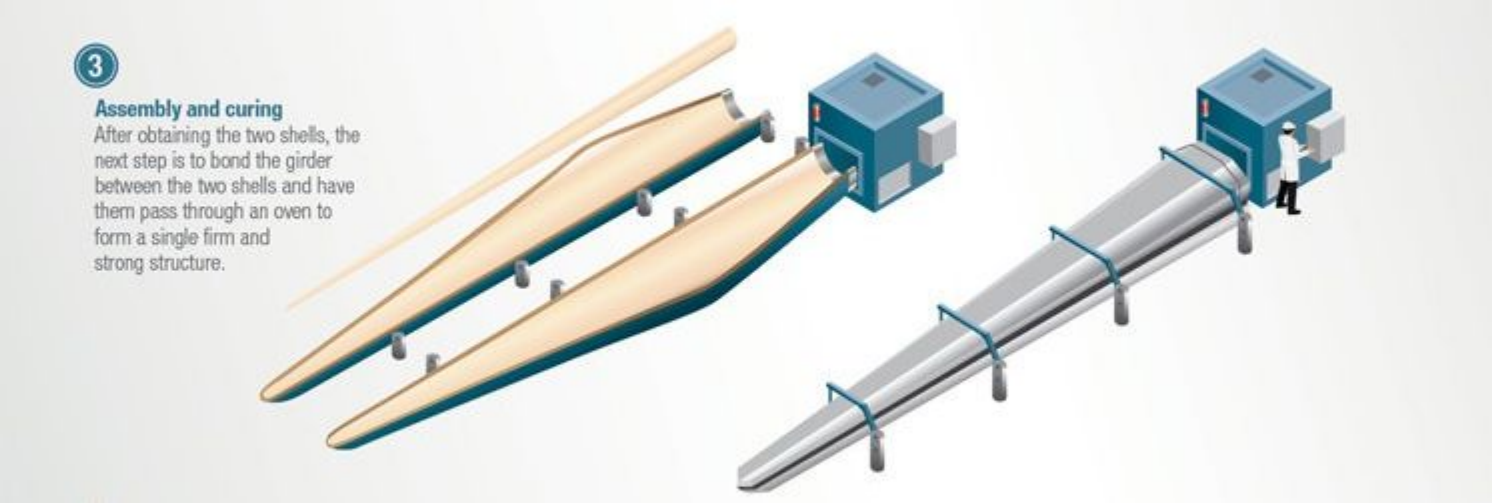
The Elephant In The Room



Wind Turbine Blade Construction



Wind Turbine Blade Construction - cont

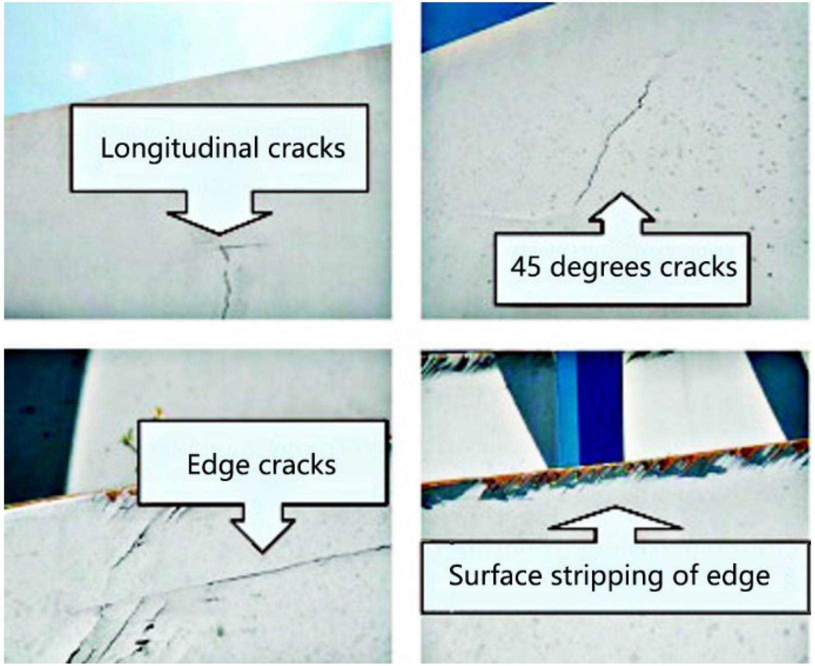


Wind Turbine Blade Construction - cont

Process: Leading Edge Erosion

A different process takes place on the trailing edge leading to cracks running a significant part of the blade length.

Process: Vibration / Cracks



Blade tip speed in excess of 200 mph on larger turbines which suffer worse vibration!

Blade Maintenance

What materials are used?

Most blades are made with fibreglass-reinforced polyester or epoxy. Carbon fibre or aramid (Kevlar) is also used as reinforcement material. Nowadays, the possible use of wood compounds, such as wood-epoxy or wood-fibre-epoxy, is being investigated.

How is maintenance carried out?

There are two types of maintenance: preventative and corrective. The former consists of periodic inspections to determine the condition of the blades and identify any damage. These checks are made using different techniques â□□ from the ground, with high-precision telephoto lenses, climbing the blades with ropes, cranes or lifting platforms and remotely, by using drones. Corrective maintenance meanwhile consists of the repair or reconstruction of the blades and *nacelles* to correct any damage that appears, both on the surface and within the structure.

How are the blades repaired?

Wind turbine blades can suffer cracks, damage caused by the impact of lightning and birds or openings in the leading or trailing edge, among other damage. The repair tasks are performed by workers at height, who hang from the blades with ropes or are lifted up to them on suspended platforms. At present, alternative repair and cleaning systems, such as drones, are being looked into to prevent operators from having to climb up to the turbines.

Process: Sanding

Repair Epoxy Datasheet

vPvB = Very Persistent and Very Bioaccumulative

Procedure used to derive the classification according to Regulation (EC) No. 1272/2008 [CLP/GHS]

Classification	Justification
Acute Tox. 4, H302	Calculation method
Skin Corr. 1B, H314	Calculation method
Eye Dam. 1, H318	Calculation method
Skin Sens. 1, H317	Calculation method
STOT RE 2, H373	Calculation method
Aquatic Chronic 1, H410	Calculation method

Full text of abbreviated H statements

H302	Harmful if swallowed.
H312	Harmful in contact with skin.
H314	Causes severe skin burns and eye damage.
H315	Causes skin irritation.
H317	May cause an allergic skin reaction.
H318	Causes serious eye damage.
H319	Causes serious eye irritation.
H351	Suspected of causing cancer.
H373	May cause damage to organs through prolonged or repeated exposure.
H400	Very toxic to aquatic life.
H410	Very toxic to aquatic life with long lasting effects.
H412	Harmful to aquatic life with long lasting effects.

Full text of classifications [CLP/GHS]

Acute Tox. 4	ACUTE TOXICITY - Category 4
Aquatic Acute 1	SHORT-TERM (ACUTE) AQUATIC HAZARD - Category 1
Aquatic Chronic 1	LONG-TERM (CHRONIC) AQUATIC HAZARD - Category 1
Aquatic Chronic 3	LONG-TERM (CHRONIC) AQUATIC HAZARD - Category 3
Carc. 2	CARCINOGENICITY - Category 2
Eye Dam. 1	SERIOUS EYE DAMAGE/EYE IRRITATION - Category 1
Eye Irrit. 2	SERIOUS EYE DAMAGE/EYE IRRITATION - Category 2
Skin Corr. 1B	SKIN CORROSION/IRRITATION - Category 1B
Skin Irrit. 2	SKIN CORROSION/IRRITATION - Category 2
Skin Sens. 1	SKIN SENSITISATION - Category 1
STOT RE 2	SPECIFIC TARGET ORGAN TOXICITY - REPEATED EXPOSURE - Category 2

Date of issue/ Date of revision : 21/03/2022

Process: Disposal

While manufacturers are frantically seeking the ‘re-cycleable’ turbine blade, today the majority end up in landfill where Bisphenol A is leached out into groundwater.

Process: Fire

Nearly 120 wind turbines catch fire each year, according to research in 2014 - ten times the number reported by the industry. The figures, compiled by engineers at Imperial College London and the University of Edinburgh, make fire the second-largest cause of accidents after blade failure.4 Aug 2022

How Much Bisphenol A?

Method A: (German EPA Report - updated for 2023)

The EU produces some 347,000 tons of Bisphenol A,

15% of this goes into wind turbine blade production as epoxy resin so 52,050 tons pa, of which 12.39 tons pa is calculated as emissions.

23% of the EU fleet of turbines is in the UK (WindEurope)

2.85 tons pa Bisphenol A emissions for the UK wind turbine fleet

Method B: (Danish EPA Report based on manufacturer's figures)

4,400 wind turbines in Denmark produce .66 tons of microplastics, so 11,000 in UK produce 1.650 tons pa of which 30 to 40 % is Bispenol A

0.577 tons pa Bisphenol A emissions for UK wind turbine fleet

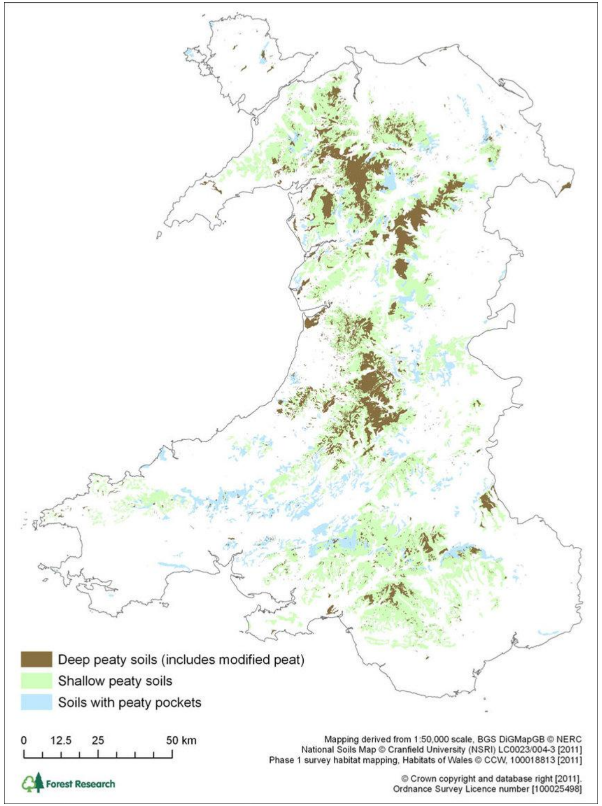
How Much Bisphenol A?

It really does not matter which method you believe:

1 kg of Bisphenol A makes 10 billion litres of water unusable!!

7 kg of Bisphenol A would make LLyn Celyn unusable!!

Environment?



CAA suggests the turbulent zone from wind turbines is 5 x the diameter of the base. That can therefore be considered the direct fall out zone ito which microplastics are carried.

The leaching of Bisphenol A from microplastics is a well known process that is dependent on pH and temperature.

Leaching is known to be accelerated in acidic conditions. This is one of the reasons it is so dangerous by ingestion.

Peat is an acidic environment!

Health & Bisphenol A

- In April 2023, EFSA published a re-evaluation of BPA's safety, significantly reducing the tolerable daily intake (TDI) set in its previous assessment in 2015.
- At the time, the TDI was made temporary as EFSA's scientists identified a number of data gaps and uncertainties, which they committed to reassess when new data became available, in particular a two-year chronic study from the US National Toxicology Program research programme.
- Based on all the new scientific evidence assessed, EFSA's experts established a TDI of 0.2 nanograms (0.2 billionths of a gram) per kilogram of body weight per day, replacing the previous temporary level of 4 micrograms (4 millionths of a gram) per kilogram of body weight per day.

Conclusion

While there are many other sources Bisphenol A, there is no more potent unregulated delivery system to spread toxins into the environment.

Consequences:

For farmers - Routine blood testing, quarantine, and slaughter of livestock, if recovery is not possible. (West Coast of Jutland, Denmark, confirmed by Danish EPA).

“Endocrine disruptors are chemicals that can interfere with the endocrine system, which is responsible for regulating hormones in the body. This disruption can lead to a wide range of adverse health effects, including developmental and reproductive issues, metabolic disorders, and even cancer” - EC Regulation 2023/707

Far from saving future generations, wind turbines could prevent them!

The Green Warriors of Norway (NMF)
Norges Miljøvernforbund (NMF)
[redacted]
NORWAY
www.nmf.no

Bergen, 15.02.2021

ECHA European Chemicals Agency
Telakkakatu 6
[redacted]

REACH – Comments and documentation

4,4'-isopropylidenediphenol (Bisphenol A)
and structurally related bisphenols of similar concern for the environment

Green Warriors of Norway/Norges Miljøvernforbund (NMF) raise several concerns regarding the increased use of Bisphenol A (BPA) and related chemicals and their impact on onshore and offshore environment and ecosystems. Much of the current and future impact will come from relatively new sources, and from sources that will increase in new areas and environments. One of the main sources of concern is from micro and nano sized particles released into the environment from epoxy-based products by erosion. Such particles that contain BPA related substances will protect its containing chemicals and protect them from degradation while they remain inside the particle materials, and like a Trojan Horse, be released into the food chain through organisms when in contact with their digestive system. It is also concerning that research show that BPA do generational harm to organisms according to a recent study of Rainbow trout.

These factors and more raise serious concerns as the development and placement of new installations reliant upon BPA containing epoxy structures reaches new frontiers with harsher and more challenging weather conditions. While chemicals like BPA in its pure form is degraded normally in a normal environment, salt water and colder temperatures in more arctic and sub-arctic environments will likely impact the rate of degradation significantly, which make them remain a potent biochemical pollutant for a much longer period than in more tempered environments. Within the protection of a micro-sized particle, they will remain a potent biochemical pollutant significantly longer than the chemical in its pure form.

With micro and nano sized particles found in larger and larger quantities on the farthest parts of the planet, from the furthest away glaciers to sediments on the deepest seabed, the concern is that our human impact on the various onshore and offshore environments accumulate and is irreversible.

We therefore need much stricter regulations and also serious incentives for the industry to find better alternatives and in the meantime stop the placement of new installations that release micro and nano sized particles containing BPA and similar chemicals to the environment.

You will find our concerns and demands in more detail on the following pages.

[redacted]

Index

[redacted]

Summary and demands

We will in our comments show that epoxy compounds is a Trojan Horse regarding to the spread of Bisphenol A (BPA, EC No.: 201-245-8 CAS No.: 80-05-7, 4,4'-isopropylidenediphenol1) to the environment and to our food chain.

Regarding the concerns we raise, we will put forth some demands in accordance with a precautionary principle. Based on the documentation we present in this brief, we are significantly concerned for the biochemical pollution BPA can cause in unknown proportions in regard to the environment, biodiversity, marine and fresh water sources, and the food chain we all are dependent upon.

We do ask on what scale is BPA levels a threat as a biochemical pollutant in different environments and towards different food chains? Do we as humans have enough knowledge to predict long term effects and harm?

> *"This is the first systematic review, to our knowledge, to assess and quantify MP contamination of seafood and human uptake from its consumption, suggesting that action must be considered in order to reduce human exposure via such consumption. Further high-quality research using standardized methods is needed to cement the scientific evidence on MP contamination and human exposures.*
>
> *Seafood is an important source of protein for populations around the world, and it may be time to implement the precautionary principle (Kriebel et al. 2001), based on the existing scientific evidence, and take steps in policy, industry, and society to minimize human exposures to foodborne MPs where possible."* [1]

Our demands below is sound and reasonable and is based on a precautionary principle. We need more strict regulations to avoid as much BPA and BPA in a combination with micro and nano sized particles of epoxy plastics released into the environment as possible.

Here are our demands:

1. We would like the placement of new large-scale installations that may cause the release of BPA and related chemicals into the environment may stop, **but acknowledge that strict regulation and standards must be put in place to reduce the impact on the environment, ecosystems, food chain and on human health.**
   Scientific research must be prioritized where there is a lack of knowledge. A proper risk assessment must be conducted before new projects that may cause release of BPA and similar chemicals to the environment. All deployment of epoxy related industries must be put on halt until proper scientific standards are met to show them safe to the environment, climate, biodiversity and human health. This applies to both production, use and dismantling, recycling and deposit of such materials.

2. **Complete product declaration on all products that contain BPA and similar chemicals must be present and follow the product on all stages from production until its recycled and reused or deposited.** The product declaration should also reflect restrictions and hazards through

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[redacted]

its intended life cycle, also including terms of application for sales and transfer of goods in accordance with applying directives.

The terms of a product declaration must include the following:

- Data sheet as a product declaration of amount, percentage, weight and volume of BPA and similar chemicals for all industries excluding food purposes.
- Content description/product declaration on all products for Activities of Daily Living (ADL) and food purposes. This will empower all customers to take responsible consumer decisions within a health- and environmental perspective.
- Branch based product declaration complying to set life cycle standards.
- Restrictions and regulations to product declarations and import/export applications to maintain national overview and control to meet nationally and internationally environmental standards and goals. This must also adhere to the goals set in the UN sustainability goals.

Industry and branches that is large scale consumers of epoxy related materials must be the first to undergo regulations that also meets the demands of a sustainable and environmentally friendly circular economy. Regulations must also include management of waste and deposal in compliance with the appropriate EU directives.

3. Relevant information must be given to public and governing bodies and to the public in general regarding the hazards of BPA and similar chemicals to human health and to the environment. Conscious consumers, both corporate and private must be a definitive goal regarding legislation, standards and procedures regarding handling of BPA containing products within a life cycle timeframe.

4. Follow advice from WHO to decrease levels of pollutants in all water systems as soon as possible. Implement stricter levels of tolerance much earlier than 2026. The reasoning for this is based on current plans to implement new installations that contain BPA-related materials both onshore and offshore. This is most significantly related to wind power generation where the turbine blades are increasing in both size, volume and numbers on an exponential rate. There is a significant problem with micro particles released into the environment due to Leading Edge Erosion (LEE). As we will show other places in this brief, this is potentially a much more environmental risk for the eco systems and our food chain than the same chemicals in their pure form due to the Trojan Horse effect.

5. Scientific research into the environmental and health related effects must be prioritized. We do have too little knowledge, especially towards long time effects, and the data we do have available show negative effects of grave concerns. Micro particles of epoxy, rubber, other plastics do seem to accumulate in the environment for each and every year, and thus also remain an ever growing and lasting environmental problem. Especially relevant to highlight the issues at hand is found in the following three quotes;

- ***"Bisphenol A in eggs causes development-specifc liver molecular reprogramming in two generations of rainbow trout"*** [2]

[2] https://www.researchgate.net/publication/320630432_Bisphenol_A_in_eggs_causes_development-specific_liver_molecular_reprogramming_in_two_generations_of_rainbow_trout/fulltext/59f37f8ca6fdcc075ec349ab/Bisphenol-A-in-eggs-causes-development-specific-liver-molecular-reprogramming-in-two-generations-of-rainbow-trout.pdf?origin=publication_detail

[redacted]

- ***"An increase in temperature or a pH change can cause the ester bonds between the BPA molecules in polycarbonate plastic and epoxy resin to be broken through hydrolysis and thus release BPA to the environment."*** [3] [4]
- (Original text-Swedish) *"Effekter från intag av plast har konstaterats för växt- och djurplankton, musslor, marina maskar, kräftdjur, fisk och fåglar. Biologiska effekter kan också orsakas av att tillsatskemikalier, som används för att ge vissa egenskaper till plasten, läcker ut och tas upp. På samma sätt kan monomerer och biprodukter som finns kvar i plasten från framställningsprocessen läcka ut. Dessutom så kan även kemikalier från den omgivande miljön, såsom långlivade organiska föroreningar ofta med hög affinitet till plast, adsorberas till partikelytan."*
  (Our translation) *"**Effects from consumption of plastics has been ascertained for phytoplankton and zooplankton, mussels, marine worms, shellfish, fish and birds.** Biological effects can also be caused by added chemicals, that is used to give certain characteristics to the plastic material, is released and absorbed. In the same way, monomers and by-products from the production process can leak out. External chemicals from the surrounding environment, such as long-lasting organic pollutants with high level of affinity to plastic, is to be absorbed to the surface of the plastic particle."* [5]

There must be set significant effort and resources towards scientific research that is aimed at establishing possible effects and mechanisms that can secure sound and environmentally friendly products and procedures.

The impact from BPA to our environment and food chain

The amounts of BPA and similar chemicals released to the environment can be enormous due to the huge increase in use of epoxy related materials in challenging environments. The research we refer, do show negative impact on the food chain at large, from the smallest plankton to large mammals, and even humans. If phytoplankton is significantly affected, their ability to capture CO_2 and release oxygen may similarly be affected. BPA is also shown to have generational impact on organisms.

The Trojan Horse effect in micro particles keep the chemicals inside shielded from environmental impact, and thus reduce the degradation of the chemicals. When consumed by organisms they are released into the organism when in contact with their digestive, often acidic fluids.

> *"An increase in temperature or a pH change can cause the ester bonds between the BPA molecules in polycarbonate plastic and epoxy resin to be broken through hydrolysis and thus release BPA to the environment."* [6]

Another problem with micro and nano sized particles is that they likely stay in the upper levels of the water body much longer and therefore is more likely be able to be consumed and absorbed into by small plankton and organisms and accumulated up through the food chain. Therefore, such micro and nano

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[3] https://www.researchgate.net/publication/306184402_Human_exposure_to_endocrine_disrupting_compounds_Their_role_in_reproductive_systems_metabolic_syndrome_and_breast_cancer_A_review

[4] https://diegofdezsevilla.wordpress.com/2014/07/17/could-plastic-debris-coarse-fine-and-molecules-polymers-affect-oceans-functions-as-climate-regulator-co2-sink-albedo-evaporation/

[5] https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6772-4.pdf?pid=20662

[6] https://www.researchgate.net/publication/306184402_Human_exposure_to_endocrine_disrupting_compounds_Their_role_in_reproductive_systems_metabolic_syndrome_and_breast_cancer_A_review

[redacted]

sized particles do potentially represent a much more significant threat to the environment than each chemical in its pure form. The micro and nano sized particles in itself can be a serious health issue to the affected organisms, not to mention the added impact from contained chemicals. Brain damage and behavioral disorders in fish induced by plastic nanoparticles delivered through the food chain is recorded by scientists. [7]

The potential risks from BPA are not only connected to life and health only, but may also affect the planets potential to collect CO2 from the environment and also only its ability to produce oxygen through the mechanisms of phytoplankton.

> *"**Effects from consumption of plastics has been ascertained for phytoplankton and zooplankton, mussels, marine worms, shellfish, fish and birds.** Biological effects can also be caused by added chemicals, that is used to give certain characteristics to the plastic material, is released and absorbed. In the same way, monomers and by-products from the production process can leak out. External chemicals from the surrounding environment, such as long-lasting organic pollutants with high level of affinity to plastic, is to be absorbed to the surface of the plastic particle." (original text in Swedish – our transl.)* [8]

Researchers has discovered plastic microparticles in the digestive system of deep sea schrimp as far down as 11 km below the surface in and around the Pacific. Over 72% of the schrimp collected had one or more plastic microparticles in their body. Micro and nano sized plastic particles can now be found in every far away corner of our planet. [9]

> *"Seafood is an important source of protein for populations around the world, and it may be time to implement the precautionary principle (Kriebel et al. 2001), based on the existing scientific evidence, and take steps in policy, industry, and society to minimize human exposures to foodborne MPs where possible».* [10]

> *"**Upon uptake, micro- and nanoplastics can reach the brain**, although there is limited information regarding the number of particles that reaches the brain and the potential neurotoxicity of these small plastic particles".* [11]

> *"Although the transport of hydrophobic contaminants by plastic debris is not relevant in terms of masses, under authors' point of view their capability **to act as a Trojan Horse** for these contaminants to living organisms cannot be underestimated".*

> ***"Hence, their toxicity may be caused by the plastic polymer itself, the additives that it contains, and/or by other chemicals associated to MPs that might be released to the aquatic media".***

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[7] https://www.researchgate.net/publication/319683370_Brain_damage_and_behavioural_disorders_in_fish_induced_by_plastic_nanoparticles_delivered_through_the_food_chain

[8] https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6772-4.pdf?pid=20662

[9] https://mikroplast.wordpress.com/2019/02/28/mikroplast-i-tarmen-pa-dypvannsreker/

[10] https://ehp.niehs.nih.gov/doi/10.1289/EHP7171

[11] https://www.researchgate.net/publication/342019198_The_plastic_brain_Neurotoxicity_of_micro-_And_nanoplastics

[redacted]

In fact, the highest contribution from beached plastics to seawater corresponded to the leaching of plastic additives (flame retardants and plasticizers) followed by PCPs, being also relevant that a significant proportion of less hydrophobic contaminants can be desorbed from plastics to seawater in the first 24 h.

There are 7 mechanisms that affect the role of MPs as carriers of co- contaminants summarized by Koelmans et al. as follow:

1. *absorption – ingestion-egestion of plastic, with chemical transferred from plastic to organism*

2. *cleaning – ingestion-egestion of plastic, with an increase of chemical excreted from organism*

3. *source – plastic acting as a source of co-contaminant in the environment*

4. *sink – plastic accumulate co-contaminants from the seawater and organisms*

5. *indirect source, dietary – desorption of chemical from plastic to natural food/prey followed by ingestion of prey*

6. *dietary – uptake of chemical by ingestion of regular contaminated food (i.e., NPs), and*

7. *dermal – uptake of chemical from any medium other than plastic and natural prey. In addition to hydrophobic contaminants such as POPs, some authors investigated how MPs and plastic debris may also concentrate metals.*

This is possible due to the oxidised form of the plastic surface that can carry functionalities that may bind metals. This last finding was unexpected, and it emphasizes the necessity to further investigate the behaviour of MPs in the environment with special attention to ageing MPs.

MNPs due to their small size, similar to plankton, can be ingested by aquatic organisms, and therefore be introduced into marine food web. Setälä et al. observed that polystyrene (PS) microspheres can be transferred via planktonic organisms from one trophic level (mesozooplankton) to a higher one (macrozooplankton).

The study also confirmed the ingestion of PS based MP by mysid shrimps, copepods, cladocerans, rotifers, polychaete larvae and ciliates although some of the species ejected the microspheres after 12 h of ingestion.

MPs and NPs may also pose a risk to human health due to their potential accumulation in seafood reaching the consumers. For example, mussel Mytilus edulis have been reported as marine species able to ingest MPs.

[redacted]

However, MPs and NPs can be retained in some organs, and they may be translocated in living tissues.

Furthermore, evidence of physical size alteration of microplastics by a planktonic crustacean has been recently demonstrated. It is estimated that some of the plastics can reach concentration factors inside the organisms near to 1 million-fold increase". [12]

«Action must be considered in order to reduce human exposure». [13]

"Furthermore, phthalates and 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.". [14]

BPA levels has been observed in urine samples from humans with extremely high frequency (up till 99%) (Ye et al. 2015) [15], which indicate a which level of pollutants in the environment [16]. BPA has been found in most samples of blood, brest milk og amniotic (Vandenberg et al. , 2007) [17]. Even low levels of BPA seems to have a very negative effect on the health of humans.

«It was concluded that low doses of BPA (1 and 10 nM) inhibit adiponectin secretion by human adipocytes cultures in vitro and stimulate the secretion of inflammatory adipokines such as interleukin-6 (IL-6) and tumor necrosis factor α suggesting its possible involvement in obesity, metabolic syndrome and insulin resistance (Hugo et al., 2008; Alonso-Magdalena et al., 2011)». [18]

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[12] https://www.researchgate.net/publication/341349798_Microplastics_in_Mediterranean_coastal_area_toxicity_and_impact_for_the_environment_and_human_health

[13] https://ehp.niehs.nih.gov/doi/10.1289/EHP7171

[14] https://pubmed.ncbi.nlm.nih.gov/27504873/

[15] https://pubs.acs.org/doi/abs/10.1021/acs.est.5b02135

[16] https://www.osti.gov/pages/biblio/1470902

[17] https://pubmed.ncbi.nlm.nih.gov/17825522/

[18] https://www.researchgate.net/publication/306184402_Human_exposure_to_endocrine_disrupting_compounds_Their_role_in_reproductive_systems_metabolic_syndrome_and_breast_cancer_A_review

[redacted]

The occurrence of BPA in different types of products

BPA is used in rubber, polycarbonates (PC), but make up between 40 to 60% of the content of epoxy resin before adding the 2-component hardener. Ready hardened epoxy contains between 30 to 40% Bisphenols. The most commonly used Bisphenol is Bisphenol A (BPA).

Regarding BPA polluting the environment, it seems like the research has been concentrated around polycarbonates (PC). It also seems that the available research also has been concentrated around BPA as a free chemical in already hardened plastics.

Scientific research on the effect that PC and BPA has on the environment, nature and climate has been and still is a vast field in both volume and complexity, that also span across several fields of theme and competence. To get the overview of all these effects and contexts is an almost impossible task. Maybe this complexity has been a cover for the industry to expand this much under this kind of cover.

It is therefore of high importance to take the precautionary principle into all activities and regulations.

[redacted]

The fact that BPA enter the food chain is relatively new knowledge

It's first in recent years, science and research has concluded that epoxy plastics ends up un the digestive system of marine and aquatic species like algae, schrimps, shellfish, molluscs, fisk, ampfibians, mammals, and also land based microbes, insects and animals. This causes BPA introduced into and accumulated up through the food chain through their digestive systems.

> *"Recently, the environmental obesogen hypothesis, suggesting that environmental chemicals contribute to development of metabolic disorders in humans, including obesity, insulin resistance, type 2 diabetes, hepatic injury, dyslipidemia and cardiovascular diseases, is gaining weight*
>
> *In this context, the implementation of greater restrictions on the use of these substances in the products of daily use and the conduction of future studies to (i) identify other substances with potentially similar effects on animals and human health and (ii) investigate the mechanisms behind should be given particular consideration".* [19]

Even if the inflicted harm from BPA is well documented, it seems that we still do not have the full knowledge of the total impact on health and the environment. [20]
In all cases, it seems like epoxy plastics and compounds might act as a Trojan Horse of significant dimensions in the environment with its harmful load. This might impose severe implications for all nature, environment, climate and all earthly life itself.

In the following list we have included some of the references relevant to the subject at hand. This is only a partial list as there is much more research to be found on the various subjects within the scientific system of publications.

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[19] https://pubmed.ncbi.nlm.nih.gov/27504873/

[20] https://www.researchgate.net/publication/306184402_Human_exposure_to_endocrine_disrupting_compounds_Their_role_in_reproductive_systems_metabolic_syndrome_and_breast_cancer_A_review

[redacted]

We know that:

1. **A long range of epoxy related products is exposed to erosion which release micro and nano particles from epoxyplastics into the environment.** The most significant sources stem from the auto industry, shipping and boat industry and from the wind power industry. [21] [22] [23] [24]
2. **We do not have a thorough collected overview on the total amount of epoxy related micro and nano sized particles** released into the environment within Europe, but we can clearly estimate the amount to be in the several hundred tons range, as it **is estimated from car lacquer/coating at 225 tons in 2013.** [25]
3. **Car tires and polycarbonates (PC) do also contain BPA** [26] [27]. There is significant amounts of micro and nano sized particles released into the environment.
4. **The production of wind turbine wings are among those with the highest consumption of epoxy plastics.** In 2013, 27% (69 000 tons) of all epoxy resin went to this production, and the production and use within this segment has undergone a significant increase since then. It's further estimated that a significant increase also will come in the coming years. [28]
5. **Yearly global production of BPA is more than 10 million tonnes, and a significant increase is expected in the coming years.** [29]
6. **Our water sources, waterways and oceans are all contaminated with high levels of BPA** and related chemicals and micro and nano sized particles of epoxyplastics. [30] [31]
7. **Epoxyplastics are made with Bisphenols, mainly with BPA, which make up approximately between 30-40 % of the total product by weight.** [32] [33]

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[21] https://www.sciencedaily.com/releases/2010/03/100323184607.htm

[22] https://www.researchgate.net/publication/330151272_Temporal_and_Spatial_Distributions_of_Bisphenol_A_in_Marine_and_Freshwaters_in_Turkey

[23] https://www.researchgate.net/publication/319683370_Brain_damage_and_behavioural_disorders_in_fish_induced_by_plastic_nanoparticles_delivered_through_the_food_chain

[24] https://www.researchgate.net/publication/343209522_Leading_edge_erosion_of_wind_turbines_Effect_of_solid_airborne_particles_and_rain_on_operational_wind_farms

[25] https://epoxy-europe.eu/wp-content/uploads/2015/07/epoxy_erc_bpa_whitepapers_automotive-2.pdf

[26] https://www.researchgate.net/publication/343184657_Car_Tire_Crumb_Rubber_Does_Leaching_Produce_a_Toxic_Chemical_Cocktail_in_Coastal_Marine_Systems

[27] https://en.wikipedia.org/wiki/Bisphenol_A

[28] https://epoxy-europe.eu/wp-content/uploads/2018/11/Epoxy_Socioeconomic_Study_Main_Findings_August-2017.pdf

[29] https://www.researchgate.net/publication/306184402_Human_exposure_to_endocrine_disrupting_compounds_Their_role_in_reproductive_systems_metabolic_syndrome_and_breast_cancer_A_review

[30] https://www.miljodirektoratet.no/globalassets/publikasjoner/M176/M176.pdf

[31] https://www.researchgate.net/publication/330151272_Temporal_and_Spatial_Distributions_of_Bisphenol_A_in_Marine_and_Freshwaters_in_Turkey

[redacted]

8. **BPA and similar chemicals are very harmful for all life**, including algae, fish, invertebrates and vertebrates when introduced through their digestive systems. It is considered carcinogenic, reduces the reproductive abilities, reduces weight, may cause brain damage, cause metabolic syndrome, cause insuline resistance and more. [34] [35] [36] [37] [38] [39]
9. **Nanoplastics can penetrate the blood-brain barrier** in fish and cause altered behavior. [40]
10. **Most of the chemicals in the Bisphenol group are hazardous and have different impacts on the environment, food chain and health** [41] [42]
11. **BPA and epoxyplastics (nano- and micro sized particles) are accumulated up through the food chain**, from phytoplankton and zooplankton and up to large fish, mammals and humans. [43]
12. **Epoxyplastics will release its harmful chemical componds when introduced to the digestive system of marine- and landbased species in all levels through the food chain.** This is the main cause why micro and nano sized particles can be of more environmental harm than the same chemicals in its pure form. [44]
13. **Epoxy is broken down through hydrolysis - ie in an environment that is acidic, wet and hot such as in the gastrointestinal tract of mammals.** *"An increase in temperature or a pH change can cause the ester bonds between the BPA molecules in polycarbonate plastic and epoxy resin to be broken through hydrolysis and thus release BPA to the environment".* [45] [46]

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[32] https://epoxy-europe.eu/wp-content/uploads/2015/07/epoxy_erc_bpa_whitepapers_automotive-2.pdf

[33] https://www.epoxy-europe.eu/wp-content/uploads/2015/07/epoxy_erc_bpa_whitepapers_wind-energy-2.pdf

[34] https://www.researchgate.net/publication/320630432_Bisphenol_A_in_eggs_causes_development-specific_liver_molecular_reprogramming_in_two_generations_of_rainbow_trout/fulltext/59f37f8ca6fdcc075ec349ab/Bisphenol-A-in-eggs-causes-development-specific-liver-molecular-reprogramming-in-two-generations-of-rainbow-trout.pdf?origin=publication_detail

[35] https://forskning.no/kjemi-miljogifter-hjernen/bisfenol-a-kan-skade-nyfodte-hjerner/743277

[36] https://www.sciencedirect.com/science/article/abs/pii/S0300483X11003453

[37] https://www.researchgate.net/publication/319683370_Brain_damage_and_behavioural_disorders_in_fish_induced_by_plastic_nanoparticles_delivered_through_the_food_chain

[38] https://www.sciencedaily.com/releases/2010/03/100323184607.htm

[39] https://www.researchgate.net/publication/306184402_Human_exposure_to_endocrine_disrupting_compounds_Their_role_in_reproductive_systems_metabolic_syndrome_and_breast_cancer_A_review

[40] https://www.researchgate.net/publication/319683370_Brain_damage_and_behavioural_disorders_in_fish_induced_by_plastic_nanoparticles_delivered_through_the_food_chain

[41] https://www.miljodirektoratet.no/globalassets/publikasjoner/M176/M176.pdf

[42] https://www.researchgate.net/publication/343184657_Car_Tire_Crumb_Rubber_Does_Leaching_Produce_a_Toxic_Chemical_Cocktail_in_Coastal_Marine_Systems

[43] https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6772-4.pdf?pid=20662

[44] https://www.researchgate.net/publication/319683370_Brain_damage_and_behavioural_disorders_in_fish_induced_by_plastic_nanoparticles_delivered_through_the_food_chain

[45] https://bora.uib.no/bora-xmlui/handle/1956/21135

[46] https://www.researchgate.net/publication/306184402_Human_exposure_to_endocrine_disrupting_compounds_Their_role_in_reproductive_systems_metabolic_syndrome_and_breast_cancer_A_review

[redacted]

14. **The degradation period of epoxy and epoxy related materials in nature can be very long**, if we disregard the time its reacting to the chemicals in the digestive systems in organisms. This is of significant concern, as it is both accumulated into the environment and its chemical package is accumulated up through the food chain. [47] [48]
15. **UV-based filtrations systems doesn't degrade epoxyplastics**, and thus, BPA contained inside particles of epoxy will likely remain undamaged throughout the filtration process in facilities for purification- and drinking water.
16. **When the 2-component process is finished, not all the initial BPA is hardened** and will remain inside the material in its pure form. This might be small amounts but it is still a major concern due to the Trojan Horse Principle mentioned above.
17. **BPA has a relative long degradation period in water**, especially in salty sea water at temperatures sub 25 degrees Celsius. This is a significant concern given that the northern parts of Europe and Scandinavia has even lower temperatures than that, especially during the autumn and winter season. In an arctic and sub arctic climate very low temperatures will be present most of the year, which may give a more severe negative impact on the environment than in more tempered parts of Europe. [49]
18. **It may also be of concern that micro and nano sized particles from all corners of the earth may find its way to the same areas, so it is also important that countries and regions outside Europe implement stricter regulations as well.** [50]

[47] https://www.sciencedaily.com/releases/2010/03/100323184607.htm

[48] https://diegofdezsevilla.wordpress.com/2014/07/17/could-plastic-debris-coarse-fine-and-molecules-polymers-affect-oceans-functions-as-climate-regulator-co2-sink-albedo-evaporation/

[49] https://www.researchgate.net/publication/334505340_Degradation_of_Bisphenol_A_in_Natural_and_Artificial_Marine_and_Freshwaters_in_Turkey

[50] https://pubs.acs.org/doi/10.1021/acs.est.7b03889

[redacted]

Little seems to have been done on research on the combined context between the release of micro and nano sized particles of epoxyplastics to the environment and the total effects this has on the environment, food chain and on human health. Much of the research seems to be focused on either the chemical in its pure form itself, or on the particles separately. We need therefore to address more of the scientific research on the combined effects and on the effects caused by the Trojan Horse Principle.

Can micro sized plastics and BPA affect the climate?

How much of the illness and extermination within the plantbased and animan kingdom is caused by the release of micro and nano sized particles of epoxy plastics containing BPA and other harmful chemicals?

> *"So, could plastic polymers interfere with the biota involved in fixing CO2 in our oceans? And if so, what kind of impact could we expect from a disturbance in the correct performance of this biota?"*
>
> *"Even though I have not found any research aiming to look at the effect of polymers over the oceanic biota responsible of fixing CO2 and the consequent impact in the environment, there are studies showing the connections between the aquatic chemistry of seas and the biota such as temperature and acidification, which give us an idea about the impact we can expect if polymers affect Carbonate fixing biota."*
>
> *"Lead researcher Dr Thomas Mock points out that Phytoplankton, including micro-algae, are responsible for half of the carbon dioxide that is naturally removed from the atmosphere. As well as being vital to climate control, it also creates enough oxygen for every other breath we take, and forms the base of the food chain for fisheries so it is incredibly important for food security."* [51]

What if those micro and nanosized particles from epoxyplastics do hurt plancton and microbes on such a scale that it impacts the very ability of the phytoplankton to capture CO_2 and produce oxygen? The same question can also be asked regarding earthbased microbest hat is essential for the quality of the very soil the plants is reliant on to grow and capture carbon from the atmosphere? Less natural oxygen production and carbon capture will impact us all? [52]

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[51] https://diegofdezsevilla.wordpress.com/2014/07/17/could-plastic-debris-coarse-fine-and-molecules-polymers-affect-oceans-functions-as-climate-regulator-co2-sink-albedo-evaporation/

[52] https://diegofdezsevilla.wordpress.com/2014/07/17/could-plastic-debris-coarse-fine-and-molecules-polymers-affect-oceans-functions-as-climate-regulator-co2-sink-albedo-evaporation/

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Coastal and offshore based wind power may be a significant contributor of micro and nano sized particles to the environment through leading edge erosion (LEE)

The problem with the spread of toxic compounds through micro/nanoparticles from offshore wind farms is a far more significant risk in arctic and sub-arctic areas than what we experience further south in the North-Sea basin. The reason being due to a much harsher and more unstable weather conditions combined with lower temperatures and much more sub-zero conditions throughout the year. Another factor that significantly contributes to this in a more negative way is the fact that it is expected that more of the sites of offshore wind farms will be in deep waters. All these factors will contribute severely to a negative direction regarding Wind turbine blade leading edge erosion (LEE), where distance, availability and complexity of maintenance operations will unquestionably lead to longer maintenance cycles and more toxic LEE to the environment.

Even in the shallow waters in the southern parts of the North-Sea basin, the maintenance and replacing eroded and damaged wind turbine blades is an overly complex and costly operation that demands rigorous planning. There they mostly use special vessels mounted on the seabed which allow them to operate in a much wider range of weather conditions than what can be possible in deep water areas. Here we must expect the maintenance vessel and operation to be far more dependent on a narrow set of weather conditions to be present for a maintenance operation. It is therefore highly likely that offshore wind farms in the northern parts of the North Sea and further north through Sub-Arctic and Arctic parts of the ocean will have much longer intervals between maintenance, which again will lead to an exponential increase in the amounts of micro/nano-sized particles containing Bisphenol types of toxic chemicals to the environment and ecosystems.

In the northern parts outside coastal Norway there is also an added risk due to the very unpredictable Arctic low-pressure weather systems that are so difficult predict and that can arise to violent winds in a short timeframe.

A turbine blade in normal operation on land can reach speeds of 300 km/h and more. With offshore wind turbines it is estimated bigger and higher-powered wind generators and longer wind turbine blades than we have on land. Therefore, wind turbine blades will much likely operate at speeds exceeding 300 km/h more of the time. This will significantly also increase LEE from impact against airborne particles from salt, rain, and hail. More sub-zero temperature days will enhance the level of erosion even further. Another factor of concern is that there is no way to have an independent or timely independent monitoring of LEE in an offshore environment, and all monitoring must therefore rely totally upon the same companies that is economically invested in the project. This is also due to the availability of the construction itself which is out of reach from all outside monitoring. This raises a significant concern for the uncontrollable release of significant amounts of toxic micro- and nanosized particles to the environment and to the fragile marine ecosystems.

A further concern is that the amount of erosion from the wind turbine blades is exponential as a partially eroded blade release more particles than a new blade. We have also seen that large parts of the coating breaks up and fall off. Deep water wind farms will due to availability, complexity and cost of maintenance operations most likely have far longer periods between when turbine blades is replaced as there for each operator is to base upon purely economic considerations rather than environmental. This is also a very significant concern that should impact the idea and implementation of offshore wind farms in general and deep-sea wind farms especially as they will be a significant contributor of toxic micro-

and nanosized particles with high content of Bisphenol type of chemicals to the marine environment and to the fragile marine ecosystems we all depend upon. The Ocean is one of our and humanities most important food supplies, we have already put severely stress upon its many intricate and fragile mechanisms and ecosystems.

The UN Goals of Sustainable development

The UN Goals of Sustainable development is signed by a majority of the earths countries and raises the concerns for our water resources, waterways and our marine ecosystems. It is equally as important as, if not more, than our concern for climate change. Without a clean ocean, waterways and marine environment, all humanity is at risk. Introducing new and significant sources of micro/nanoparticles and toxins to our waterways and oceans inevitably lead to the fall of the civilizations inhabiting this planet. UN Goal 6 of Sustainable development concerns our drinking water and Goal 14 concerns Life Below Water. [53] [54]

[53] https://www.un.org/sustainabledevelopment/oceans/

[54] https://www.un.org/sustainabledevelopment/water-and-sanitation/

The correlation between finds in research and the many unanswered questions raise several concerns

Many of the most relevant questions remain unanswered by the current scientific research. Many finds raise several questions on the volume and speed we introduce these chemicals in their pure chemical form and in combination with micro and nano sized particles introduced and accumulated in the environment. The concerns raised on this issue is in most part in way it may affect different parts of the ecosystem and how it affects it in the totality combined with other environmental pollutants and impacts. We must as responsible humans take our direction and way forward based on a precautionary principle. If we don't, we may well be responsible for very severe and unforeseen consequences that we as humans are equally as dependent on as our fellow beings and organisms. A collapse within the very fragile ecosystems can affect us back several times. We need to implement very strict regulations on the production, sale, use and decommissioning of parts and materials containing BPA and other harmful chemicals and micro and nano sized particles of epoxy- and other plastic related materials. They do accumulate in the environment and we must prevent at all cost that we enter the point of no-return. After all, much of the impact we cause on the environment regarding micro and nano sized particles are accumulated and its impact may also be irreversible.

The biggest sources of such pollutants must be regulated first, and less harmful replacements must be incentivized for the industries involved. Furthermore, a circular economy must reduce the environmental impact. As it stands today, the wind farm industry as one of the largest polluters of micro and nano sized particles containing BPA and other harmful chemicals do fail on most and all of these factors.

The revised 2020/2184/EC Directive still doesn't comply to the recommendations set by the WHO

As of closing, we like to point out that 98/83/EC Directive on the quality of water intended for human consumption is replaced by 2020/2184/EC. [55] In the revised version, stricter regulations on BPA and plastics has been implemented. ECHA must take these into its work towards new regulations and standards.

However, it seems that the allowed values set in Directive 2020/2184/EC for BPA at 2,5 µg/l, and its allowed margin of error at 50 % on measurements in water for human consumption doesn't satisfy the recommended values set by the WHO. The margin of error set by the WHO as of 2017 is set at 0,1 µg/l.

In other words, Directive 2020/2184/EC do allow values that is 37,5 times higher than recommended by the WHO. ECHA has still a long way to go regarding the allowed values of BPA in water for human consumption before the recommendations set by the WHO can be met.

Request for action

We do hope that the concerns we have raised in this document can lead to better, more strict set of rules and regulations that aim at a better and more environmentally friendly use of BPA and similar hazardous chemicals and their use in epoxy- and plastic based chemicals. Our own future depends upon our own actions. We need better regulations now.

With green regards,
Green Warriors of Norway
Norges Miljøvernforbund

[redacted]

Ruben Oddekalv - Leader
[redacted]

<u>Caseworkers:</u>

- Jan-Erik Weinbach
- Laila Haukeland
- Arnfinn Nilsen

[55] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020L2184&from=EN

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Article

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Article

Microplastics Emission from Eroding Wind Turbine Blades: Preliminary Estimations of Volume

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Abstract: The erosion of wind turbine blades is one of the most frequently observed mechanisms of wind turbine blade damage. In recent months and years, concerns about high volumes of eroded plastics and associated pollution risks have surfaced on social networks and in newspapers. In this scientific paper, we estimate the mass of plastic removed from blade surface erosion, using both a phenomenological model of blade erosion and the observed frequency of necessary repairs of blades. Our findings indicate that the mass of eroded plastic ranges from 30 to 540 g per year per blade. The mass loss is higher for wind turbines offshore (80–1000 g/year per blade) compared to onshore (8–50 g/year per blade). The estimations are compared with scientific literature data and other gray literature sources. Using the entire Danish wind farms portfolio, we quantify the yearly mass of plastic from blade erosion to be about 1.6 tons per year, which is an order of magnitude less than that from footwear and road marking and three orders of magnitude less than that from tires. While the contribution of wind blade erosion is small compared to other sources, the results of this work underline the importance of the (A) effective leading-edge protection of wind turbines, (B) regular and efficient maintenance, and (C) the optimal selection of materials used.

Keywords: wind energy; wind turbines; microplastics; surface erosion; leading edge erosion

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1. Introduction

Wind energy is a green, secure way of energy production, but it is a young industry. The first offshore wind park was installed in 1991 (as compared to the first cars, in the 1880s, and the first airplane, in 1903). Therefore, not all the elements of the technology were “born sustainable”. This apparent fact becomes, however, hot news, when this or that element of the technology requires additional upgrade. The side effects of the sustainability transition are widely reported, become viral on social networks, and influence public opinion, with negative views toward renewable energy expansion. A famous example is the initial difficulties of recycling composite wind turbine blades [1]. While a lot of efficient blade recycling technologies now exist [2], corresponding regulations are also introduced to ensure the environmentally friendly end of life management of blades [3]; the story about the problem with the recyclability of wind blades has attracted the attention of the wider public. Another topic is the possibility of plastic particle detachment due to the erosion of wind turbine blades [4,5].

Surfaces of wind turbine blades are subject to erosion due to rain and hail impacts [6–8]. This problem has attracted the industry’s attention, and many projects have been initiated (e.g., [9]). In [6,7], some recent investigations on the mechanisms, modeling, and impact of the leading-edge erosion of wind turbine blades are discussed. Solutions for the mitigation of blade erosion are summarized in [7], including thermoplastic and hybrid thermoplastic coatings, highly viscoelastic coatings, structured interfaces to enhance the coating attachments, electroforming metallic leading-edge erosion shields, and structured nanoreinforced coatings. One of the side effects of blade erosion is that particles, detached from the blade surface due to erosion, might fall into the water (for the case of offshore wind turbines). The surface erosion of wind turbine blades has high maintenance costs and worsened aerodynamic properties [6,10], but it can also lead to small plastic particles detaching from the blade surface and falling down. The drastic expansion of offshore wind energy requires a detailed analysis of all the possible environmental effects.

In a new project called PREMISE "Preventing MIcroplastics pollution in SEa water from offshore wind" [11], supported by Velux Fonden, the process of the surface erosion of wind turbine blades is investigated with a view to the possibilities of plastic particle emission.

In this paper, a preliminary evaluation of the volume of eroded plastic is presented and compared with some literature data. The contribution of plastic particles from eroded wind blades is also compared to the overall plastic emissions in seas.

2. Data Extrapolation Challenges in Estimation of the Mass Loss

Many public and social network posts about the risks of microplastic pollution from wind blade erosion refer to the report by Solberg and colleagues [5], which was put online in 2021, without any peer review or validation. In this section, the logic and reasoning in this report are analyzed in order to evaluate the correctness of this report and provide correct estimations of microplastic emission.

In the report by Solberg and colleagues [5], a series of experiments carried out at the University of Strathclyde [12] are used as a starting point of their analysis. The observations are extrapolated for wind turbine parks, and from that, conclusions about a large volume of eroded plastics of wind energy are drawn.

Extrapolation of results from [12] to real wind turbine parks. In the publication in [12], epoxy/glass composite samples were subject to rain erosion tests and showed some loss of weight. While these results of the University of Strathclyde team were interesting from a scientific viewpoint, the experiments in no way reflect a realistic situation. Epoxy/glass composites are materials used for the structural parts of wind turbine blades. Before they are used, the composites are always covered by soft, damping coatings (typically polyurethane-based) and are never exploited as pure epoxy/glass structures. The reason is that epoxy is relatively brittle material, which can indeed show quick surface degradation and damage under high impact loading, which is why such epoxy glass composites are covered by soft coatings. The transfer of observations from pure epoxy composites to polyurethane-covered composites is in principle wrong.

Extrapolation of mass loss results from [12] on larger wind turbine blades. In the paper by Pugh and Stack [12], the authors carried out experiments on the surface degradation of epoxy glass composites under rain loading conditions. The degree of erosion was characterized by "mass loss". This means that a sample was weighted before and after the tests, and the difference was calculated. It was a relatively reasonable way of estimating surface degradation for the authors. However, such estimation cannot be extrapolated in a way of how the authors of [5] do it. Figure 1 illustrates the schema. In other words, if a sample 10 × 10 × 10 mm is subject to surface degradation (rain erosion, corrosion, or grinding) and loses 3 mm of upper layer, its mass loss is 30%. However, if a sample of 10 m × 10 m × 10 m is subject to the same surface load and loses 3 mm from the upper layer due to surface degradation (the rain is not going to become 1000 times stronger only because the sample became 1000 times bigger), its mass loss is in no way 30% but rather 0.003%. A simple transfer of the 30% rule to a larger sample (like "if a 3 year old boy grew up from 1 m to 110 cm, 10% in one year, then he will reach 10,000 m at the age of 50") is plainly wrong.

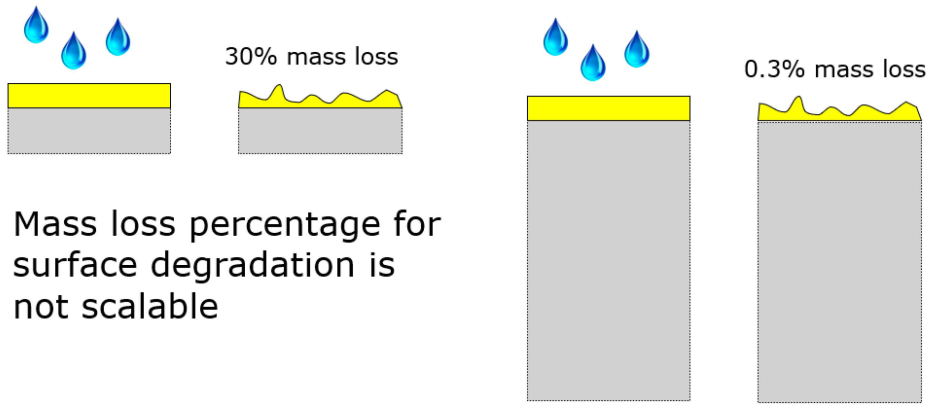


Figure 1. Why weight loss percentage cannot be extrapolated for surface degradation.

Different polymers are used in different parts of wind turbine blades. The report [5] starts with a statement about the dangers of bisphenol A (which, according to the authors, lands in the sea due to erosion). Bisphenol A is an organic synthetic compound used in formulating epoxy resin. As said, the leading-edge erosion of wind turbine blades means the degradation of protective coatings, which are polyurethane-based. Unless the degradation reaches extreme stage, and all the protective coating is worn out, the erosion does not involve the degradation of epoxy. No bisphenol A is used when producing polyurethane coatings according to all the coating manufacturers. A case when erosion continues for so long that the damage reaches even laminate is indeed possible theoretically, but this would be an extreme case, when proper maintenance of the blade is neglected. Since the surface erosion of a blade leads to a reduction in aerodynamic efficiency, reduction in energy generation, and an increase in the risk of full blade failure, this situation, when a wind park owner neglects such growing erosion and just waits until the blade fails (for which they would expect a bill of several hundred thousands of dollars for a replacement), is a rare and extreme case.

Formula for lifetime is transferred to mass loss. In the classical Springer model, the linkage between the lifetime (number of rain droplet impacts until failure) and blade velocity is described by a power function with a power coefficient of 5.7 [13,14]. Springer observed that time to first failure relates to the impact pressure as $N_I^*(P) = C * \left(\frac{S}{P}\right)^{-5.7}$, where P is the water hammer pressure, S is a material strength parameter, and C is an arbitrary constant. In most cases, we can assume that S is constant and then obtain $N_i^*(P) = C * \left(\frac{1}{P}\right)^{-5.7} = C * P^{5.7}$. Since the water hammer pressure is a linear function of velocity, Springer's model can be rewritten as $N_i^*(v) = C * v^{5.7}$. This now relates to how the number of impacts to failure follows the velocity. The authors in [5] transfer this power function of 5.7 to the volume loss of the blade due to erosion. The justification of using this exponent value is that "One report stated a potency of 5.7 for pressure change, but 5.7 is used often". Apparently, the amount of impacts until failure is in no way directly proportional to the volume of eroded material. The formula for the number of impacts until failure (i.e., fatigue strength of given material) versus velocity cannot be transferred to the volume of spalled material (one can easily imagine a situation, when a plastic sample reaches fatigue limit, without losing even a single unit of material). The temporal characteristic of the damage process (number of impacts until failure) is not connected and does not correlate with the volume of removed material. For surface degradation, the damage is localized in a small surface layer [8,15]. Even if the material is brittle, or has a low fatigue lifetime, the damaged zone will not expand into a large volume. Such an easy calculation (assuming that lifetime is inversely proportional to the volume of removed material) is plainly wrong. The correct way to calculate the volume of removed material, taking into account its properties, is presented in [15], for instance.

Confusion with power degrees: Adding kinetic energy on top of kinetic energy. According to [5], this formula (with power degree 11) is a combination of Springer's model for homogeneous materials (amount of hits to failure versus velocity) and kinetic energy correction (additional power 2). In the Springer model, however, kinetic energy is already accounted for, in the 5.7 exponent. Thus, even when assuming that all the elements are correct (while they are not), the power coefficient should not be multiplied additionally by 2.

To summarize, one should state that when extrapolating experimental observations from laboratory tests to field situations, it is important to check the comparability of the data (is the material tested the same which is used?), the transferability of the observations, and also the correctness of the mathematical transformations.

3. Qualitative Estimations of Volume of Eroded Plastics

In this section, two methods of the estimation of plastic splitting from the wind turbine blade surface due to erosion are presented; one method is based on the impact modeling and the other is based on the repair statistics. The results are compared with the literature data.

3.1. Estimation via Liquid Impact Mechanics and Probabilistic Model of Erosion

The roughening of and plastic material removal from the surface take place as follows [6,8]. A rain droplet hitting a wind turbine surface causes a local stress increase, the formation of stress waves, and the deformation of polymers. Rain droplets, hail, and sand hit wind turbine surfaces day after day, year after year. This repeated surface deformation leads to fatigue damage, microcracking, and the splitting of small polymer parts. Wind turbine blades are coated by polymer layers which protect their load bearing parts, but they still degrade due to rain and hail erosion.

An exact finite element-based model of the roughening of wind turbine blade surfaces is given in [8,15]. However, this model is relatively complex and requires many input data. In order to give a quick estimation of the eroded volume, Tempelis and colleagues presented a probabilistic, phenomenological model of the erosion of wind turbine blades [15]. This model is used here to estimate the volume of the removed material.

In the model [15], a simplified geometry of the blade's surface is discretized as a number of material elements. Surface erosion by multiple droplet impacts is modeled through the removal of these material elements. The impact positions of the droplets were generated as random values based on a uniform random distribution, and a probability of failure is used to determine failure and material removal. For each impact, the probability of failure p_{fail} is calculated as a Weibull probability function:

$$p_{fail} = 1 - e^{-\left(\frac{t}{t_c}\right)^k} \quad (1)$$

where t is the time under rain, t_c is the characteristic life of the coating material for the current rain conditions, and t_c can be calculated from the rain erosion data (V-N curve) or analytically. Parameter k determines the shape of the volume loss curve. The methods of the evaluation of these parameters were given in a previous paper by the authors [8,15]. The parameters are determined using the data from rain erosion testing (RET) experiments by fitting them into the RET data.

The mean size of the removed fragments must also be defined as a parameter or estimated from the measurements and literature data. The position where failure occurs is chosen randomly based on the impact location. It is assumed that an impacting droplet that causes failure affects an area with a radius equal to the droplet radius. If an impact occurs near a damaged area, the failure position is chosen randomly but in a way that increases the size of the damaged area. This is to resemble the failure observations from RET. When failure occurs, the heights of the affected material points are reduced by the removed fragment size. Figure 2 shows the schema of how the height of a given point is reduced as a result of droplet impact and the resulting damage. The model parameters were calibrated by RET (rain erosion tester) datasets of viscoelastic polyurethane coatings.

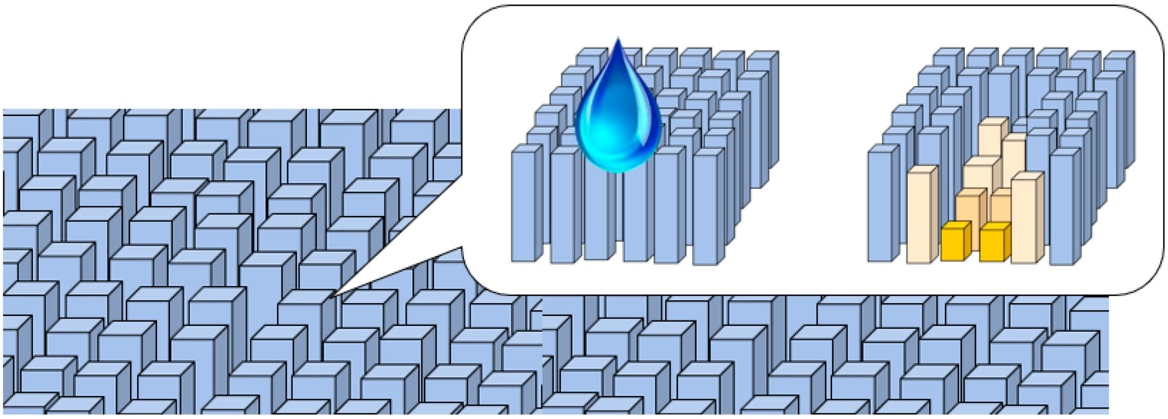


Figure 2. Schema of the discretized model of surface roughening due to droplet impact used in [15].

Figure 3 shows the calculated roughness evolution of the blade surface. The results of this simulation are shown in Figure 4, with coating volume loss increasing with time. Assuming an average tip speed of 90 m/s, 1000 mm of rain annually, and a mean rain intensity of 1 mm/h, one can obtain 15 mm^3/cm^2 volume loss per year.

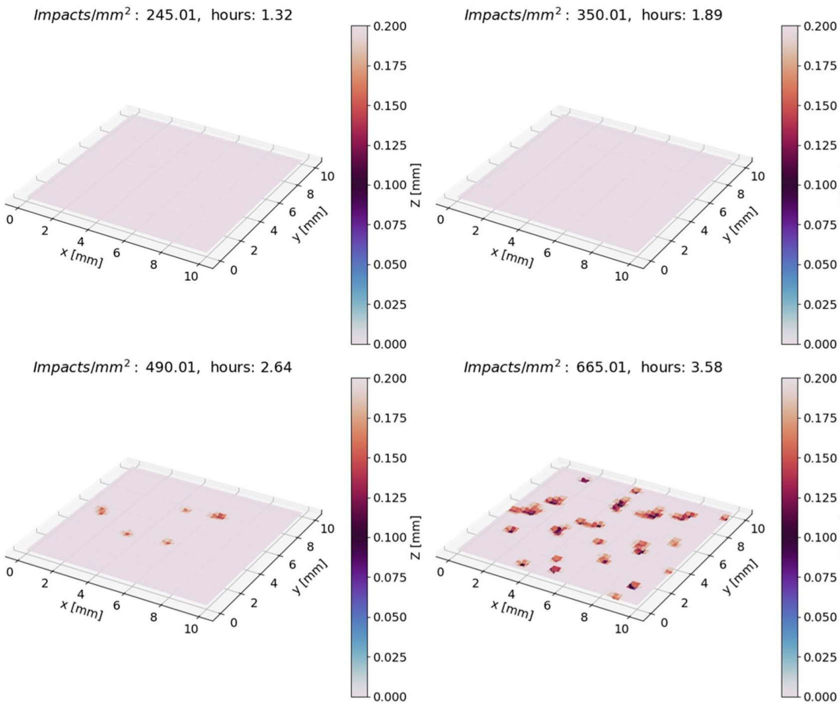


Figure 3. Predicted evolution of surface damage by using 3D surface roughness plots of the coating's surface. Reprinted from [15].

For the area 10 m × 50 mm (full leading-edge surface), this leads to 75 cm^3. This value is comparable and in the range of the values given in Section 3.2. So, it gives 75 g per blade per year. Apparently, by using a more detailed modeling of wind velocity and rain intensity, this model can be made very exact.

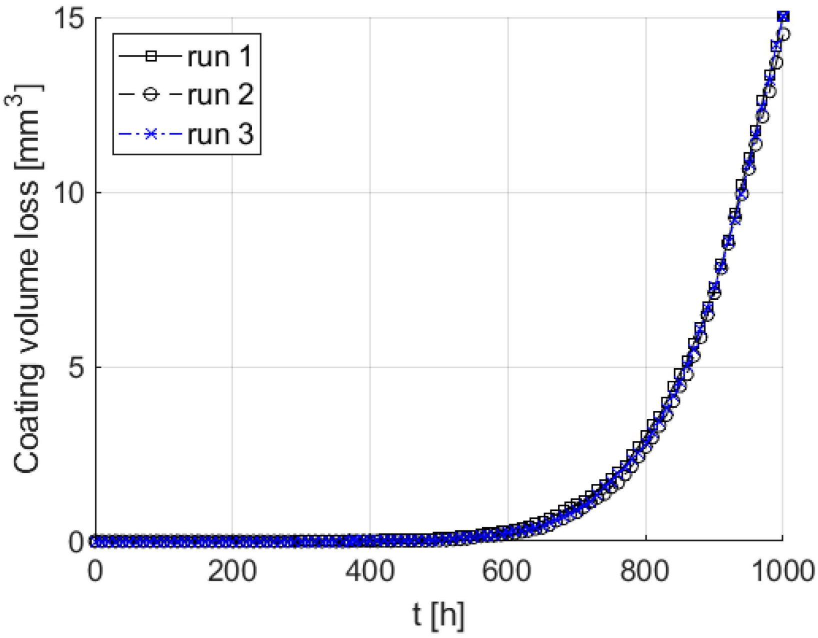


Figure 4. Estimated volume loss per area as a function of time under rain for a tip speed of 90 m/s and a mean rain intensity of 1 mm/h. Reprinted from [15].

The model is further validated by comparing it with the erosion depth measurements from the RET data. The RET data are available from the project DURALEDGE [9] and contain measurements for the end of incubation and breakthrough times from three samples tested in an R & D-style test machine. Four polyurethane-based coatings were tested, which are named 269-1, 269-3, 269-4, and 269-5. For the tests, the maximum tip speed was around 125 m/s, and the mean droplet size was 2.4 mm with a flow rate of 65 L/h. The predictions of the model for the maximum depth of erosion are performed by using the calibrated parameters from [15], and the required input is the number of impacts per mm^2 or the total rain impingement from the V-N or V-H curve of each coating. Since the end of incubation and breakthrough measurements are extracted from an area of the samples with approximately a tip speed of 120 m/s, the number of impacts per mm^2 or the total rain impingement is extracted for this tip speed. The number of impacts per mm^2 for a tip speed of 120 m/s, as extracted from the V-N curves, was 146.56, 300.347, 251.319, and 1111.52 for coatings 269-1, 269-3, 269-4, and 269-5, respectively. The number of impacts per mm^2 can be directly related to testing time by using equations to calculate the impact rate for the applied testing conditions for the R & D-style RET. The comparison graphs are presented in Figure 5. The depth for the breakthrough of the coatings is considered at 0.2 mm, which is the thickness of the coating layers in the RET samples. Three runs are used to account for the randomness in the impact positions and failure probability.

The predictions are in the range of the experimental measurements for both the end of incubation and breakthrough times. Coating 269-4 reaches breakthrough almost immediately after the end of the incubation, and the predictions are not able to capture this. However, the end of incubation time is predicted well. The predictions for the other coatings are reasonable and validate that the model can provide reasonable predictions.

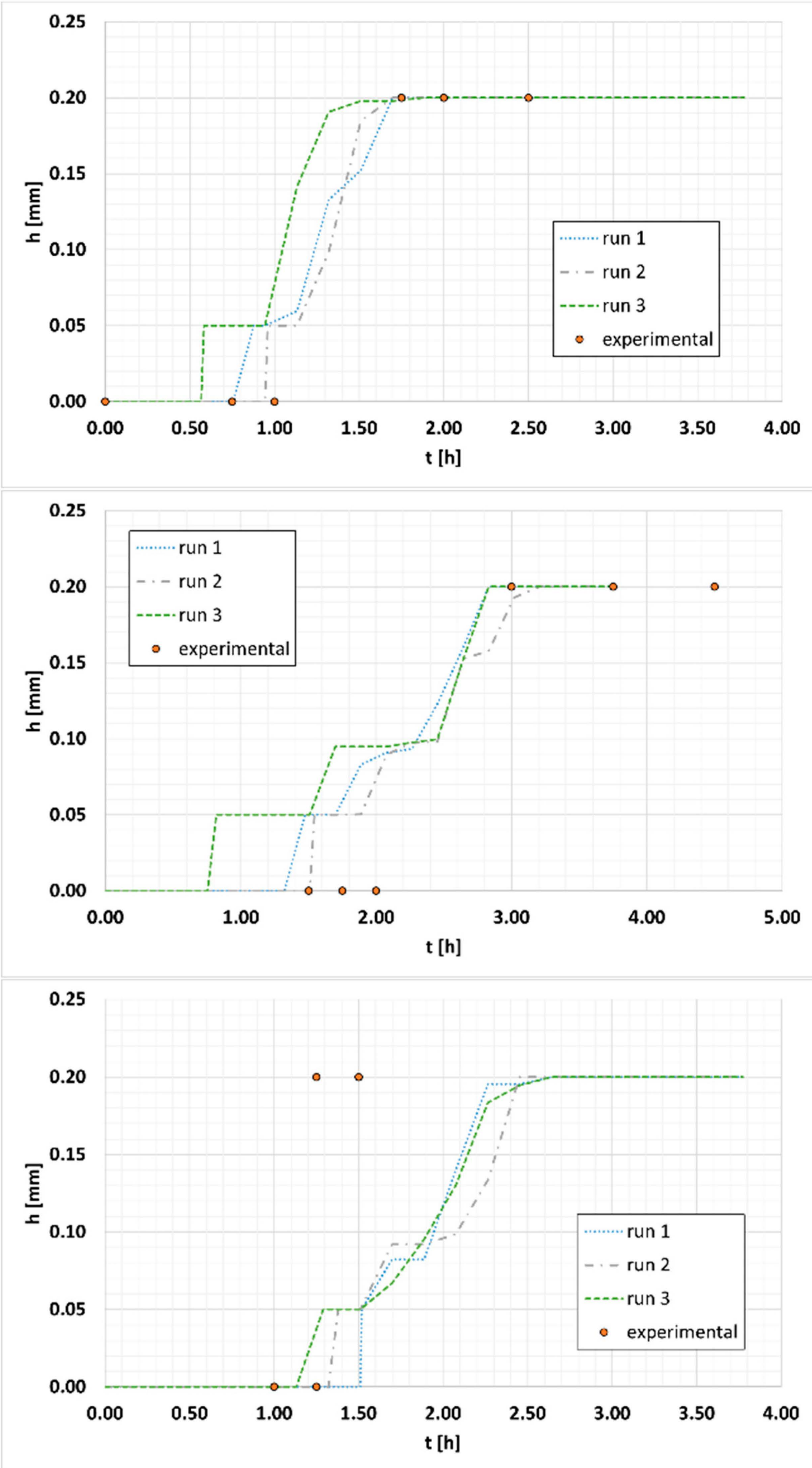


Figure 5. *Cont*.

(D)

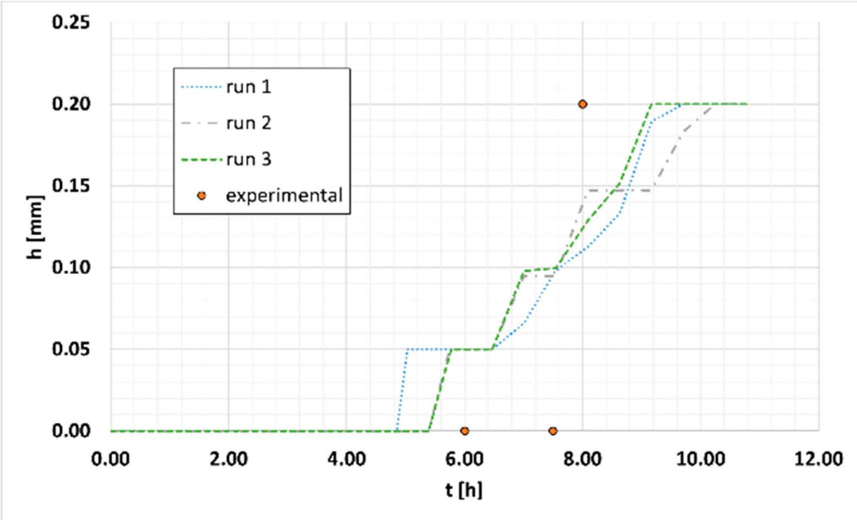


Figure 5. Comparison of erosion depth predictions with experimental RET data for coatings 269-1 (**A**), 269-3 (**B**), 269-4 (**C**), and 269-5 (**D**).

3.2. Estimation via Repair Statistics

Another way to estimate the volume of removed plastic is to use the repair and maintenance statistics. The average frequency of blade repairs, distributed over various damage mechanisms, is known and available from various databases and surveys [10,16,17]. Wind turbine blade repair is very expensive, so the repair teams are only called when they are necessary and the blade's degradation/erosion is visible, detectable, and could start influencing the energy generation of the wind turbine. The frequency of repair (F times per year) multiplied by the average volume of the removed blade material each time the repair team arrives is equal to the volume of eroded plastic per year.

According to the estimations in [10,16,17], the minor repair of wind blades is required on average 0.456 times per year per blade. This is the value taken from the 2010 to 2015 data. Probably, the new LEPs provide better protection, but the wind turbine blades are often much larger, and wind turbines are installed in more challenging regions, so the number should still be used as a conservative estimation. The team of the project PREMISE [11] contacted several service companies and asked them to share their experience, i.e., how large an eroded region is, how deep the eroded area is, and when they arrive to the repair site.

The estimations are as follows:

- Onshore: length of eroded region is of the order of 1.5. . .2 m; depth is 1–2 mm and width is 20–50 mm. Repair every 2 years.
- Offshore: length of eroded region is of the order of 4 up to 10 m; depth and width are the same. The scatter depends on sites, WTG models, blades, and coatings.

The volume of the removed coating material, per year, can be estimated by the following formula:

$$v = klwh\mathrm{F} \tag{2}$$

where l, w, h—length, width, depth of eroded region, k—coefficient of shape of eroded hole, and F—frequency of repairs per year (i.e., frequency of finding such eroded areas). The estimation of the coefficient of shape is shown in Figure 6. The blade coating is not removed fully but rather in craters, and the distribution of these craters is quite irregular: there is high crater density or almost full removal on the leading-edge line and low crater density, and almost fully intact coatings, on the sides. To take into account the low density of the craters on the sides, and also the craters instead of full removal, we multiply k by 0.5. This is a first estimation, and more exact estimations are required.

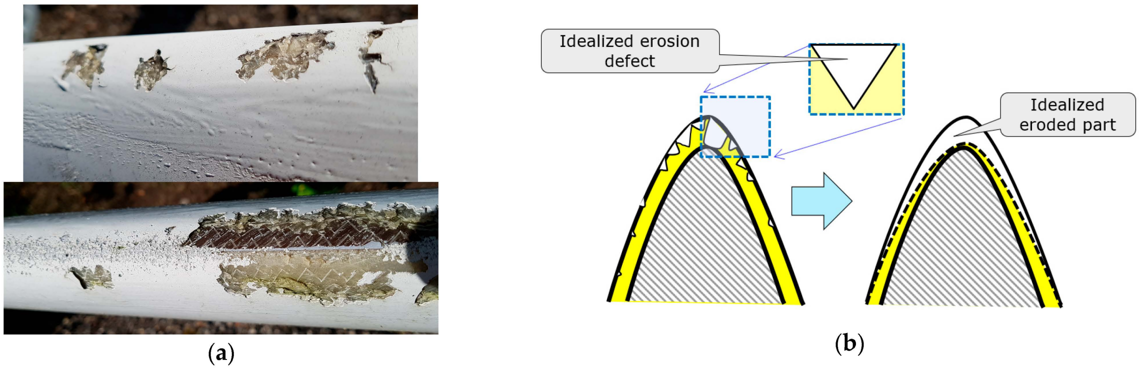


Figure 6. Examples of eroded blades (**a**), from Vindeby farm, left, photo by Jakob Bech) and schema of coefficients of shape of eroded surfaces (**b**).

Using the formula above, one can determine the volume of the removed coating material, per year, as shown in Table 1.

Table 1. Estimated volume of removed coating material based on repair statistics.

Onshore		
	Volume, cm^3	Weight, g
○ Lowest estimation, per year	8	8
○ Highest estimation, per year	50	50
○ Average	29	29
Offshore		
○ Lowest estimation, per year	80	80
○ Highest estimation, per year	1000	1000
○ Average	540	540

For the lowest estimation (if the wind park owner invests in the quick and regular repair of blades and if the wind turbine is located onshore), the small erosion of a blade, it is 8 cm^3 per year. This corresponds to the analytical estimation above.

For upper bound (extremely high erosion; the situation when the wind park owner almost neglects regular repair), it is 540 cm^3 per year. If the polyurethane density is 1000 kg/m^3, then it means 30 g to 540 g per year. In 2023, there were 6326 wind turbines in Denmark onshore and 648 offshore [18]. In order to determine the overall microplastic volume due to wind energy, we multiply these numbers (6326 onshore and 648 offshore) by the average detached volumes from the blades, presented in Table 1.

The estimated result is that all the onshore wind turbines in Denmark produce between 100 and 900 kg of polyurethane per year, on average 500 kg per year. All the offshore wind turbines emit between 200 and 1900 kg of plastic per year, with an expected average of 1000 kg per year. This means that the volume of eroded polyurethane is 1.6 tons per year.

3.3. Discussion and Comparison with Other Data

Several investigations have been carried out, with the purpose of investigating the likelihood and effects of possible microplastic emissions.

In [19], the microplastic content in sediment samples collected under and in the vicinity of an offshore wind farm (OWF, Hywind Scotland, Peterhead, UK) was assessed, with a specific focus on the occurrence and quantification of larger MPs (>300 µm), in particular those derived from the OWF infrastructure (e.g., coatings from rotor blades and leading-edge protection materials), as well as the background levels of other MPs from other sources. The authors sought to test the physicochemical effects of the established MP extraction procedure on laboratory-generated particles from coatings and quantify and characterize the extracted MPs using a combined approach of microscopy and FTIR analyses. They used reference microparticles (RMP) > 300 µm from three examples of coating materials provided by Equinor, including leading-edge protection material, top (surface) layer of rotor coating, and subsurface layer of rotor material. No detectable presence of MP contamination from coating materials used for the rotor blades or from the leading-edge protection materials was found in the analyzed fraction of the sediment samples. However, background MP contamination was detected from other sources, as thermoplastics supposedly released from other anthropogenic products.

In [20], it is written that the estimated amount released each year per blade is less than 50 g for a large onshore turbine and less than 100 g for a large wind turbine blade. This estimation is similar to the above calculation.

In [21], the following estimates are presented. The estimate by the company Key Wind Energy GmbH, Berlin, Germany, gives the erosion-related material loss to be around 67.5 kg per wind turbine over its entire twenty-year service life in the worst-case scenario (heavily stressed locations and without regular repairs of small damage). This would correspond to an annual material loss of around 3.38 kg per wind turbine.

The estimate of the company Deutsche Windtechnik, Bremen, Germany (also presented in [21]) gives similar results. They state that the blade is eroded approximately six to ten meters along the leading edge, which corresponds to around 500 g of polyurethane (PU) coating per blade, plus an additional 200 g per blade in additional layers. With three rotor blades per year, this would result in a material loss of 2.1 kg per wind turbine. Both estimations are also relatively close to the numbers presented in Section 3.

In [22], a team from the Norwegian Water Resources and Energy Directorate (NVE) sought to quantify the mass (volume) of erosion from turbine blades in Norway and came to an estimate of 200 g/blade per year. The methodology was that one windfarm which had experienced leading-edge erosion took exact measurement of all the repair material they used when they repaired their blades. Since the density of the repair material was about the same as the leading-edge erosion material, they could give a reasonable measured result of the amount of erosion the blade had experienced over seven years of operation. This was carried out for all the turbines in the wind farm.

3.4. New Observations of Wind Turbine Blade Erosion Mechanism: Spot Erosion

The estimations presented above rely on the recommendations obtained on the basis of experiences. The repair frequency presented in [17] was published in 2016 and apparently reflects observations from the late 2000s to early 2010s. Similarly, the recommendations of wind turbine service companies (service and repair every 2 years) are based on experiences from the 2000s to 2010s. Many research projects have been carried out over the last decade to improve blade protection [6,9], and new excellent coatings have been developed. On the other hand, new and bigger blades have been developed and installed. How has this changed the situation with erosion and the volume of eroded plastic?

The project team carried out interviews and discussions with wind turbine owners (WTOs) and energy companies to collect recent observations. The observations are as follows:

- Rarer repair operations. According to the WTO, practical repair occurs not every 2 years (as estimated in [17], and recommended to repair technicians, and also used in the above simulations) but rather once per 5. . .8 years. Apparently, this is related to better, newly developed LEPs.
- Changing erosion mechanisms: the introduction of new LEPs leads to changing mechanisms of their degradation. Namely, the detachment of coatings or coating parts occurs sufficiently more often than real erosion.

- Changing mechanisms of erosion: "spot" or "tiger tail" erosion. In the recent observations, eroded blades look to be not randomly eroded (with some gradient from high erosion closer to the blade tip) but rather eroded in random spots along the leading edge. Figure 7 shows what such an erosion looks like. Apparently, erosion in this case is not a random process but starts probably from some defect. It can be seen that the pits can reach laminate but still remain very localized.

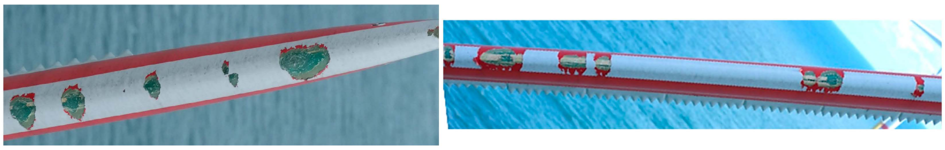


Figure 7. Erosion observations in 2023.

Apparently, the changed erosion mechanisms and much more seldom repairs mean that the amount of separated plastic is reduced by three or more times, as compared to the values estimated in Section 3.2.

Further developments of LEP/protective coatings are underway now. For instance, nanoengineered coatings developed in [23] allow for the incubation time to be extended up to 13 times. Further, new, bio-based coatings are under development now; for instance, cellulose particle-reinforced LEPs [24]. The advantage of these coatings is that they can degrade in nature without causing any negative effects or pollution (as normal, tree cellulose). Thus, with the extension of wind energy in future decades, new coatings could potentially allow for the mitigation of both blade erosion and the negative effects from the erosion.

4. Comparative Assessment of Contribution of Wind Energy to General Pollution

In order to rank the level of microplastic pollution from wind turbines, a number of reports and other publications about microplastic pollution were reviewed. According to [25], the annul emission of microplastics is up to 5.6 million metric tons, and up to 1.5 million tons appear in the world's oceans [26]. The main sources of microplastic pollution are textiles, car tires, and ship painting [27]. The data are summarized in Figure 8. The figure shows that there are three main sources of microplastic pollution: car tires, road markings, and pre-product plastics. The data provide the maximum possible amount of microplastics.

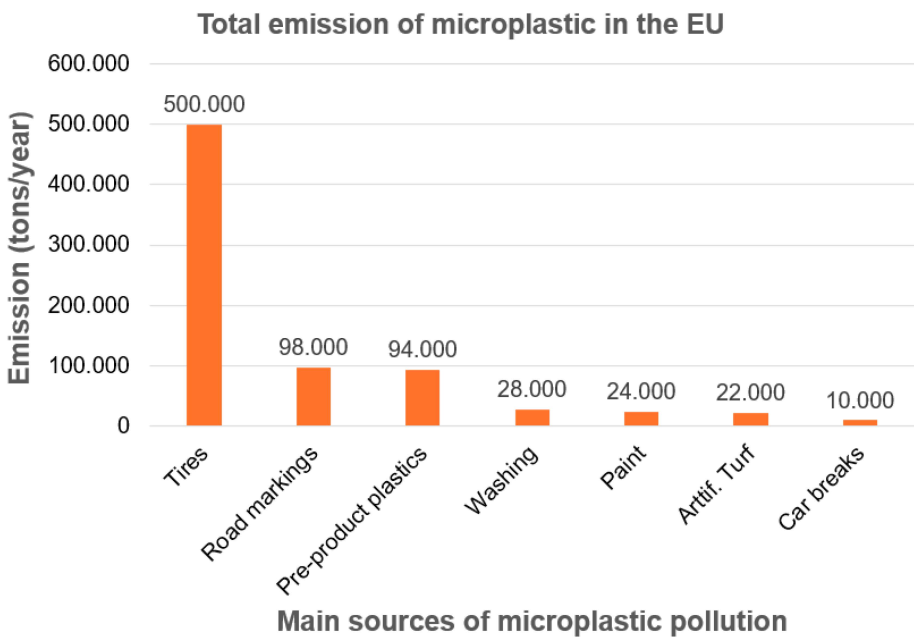


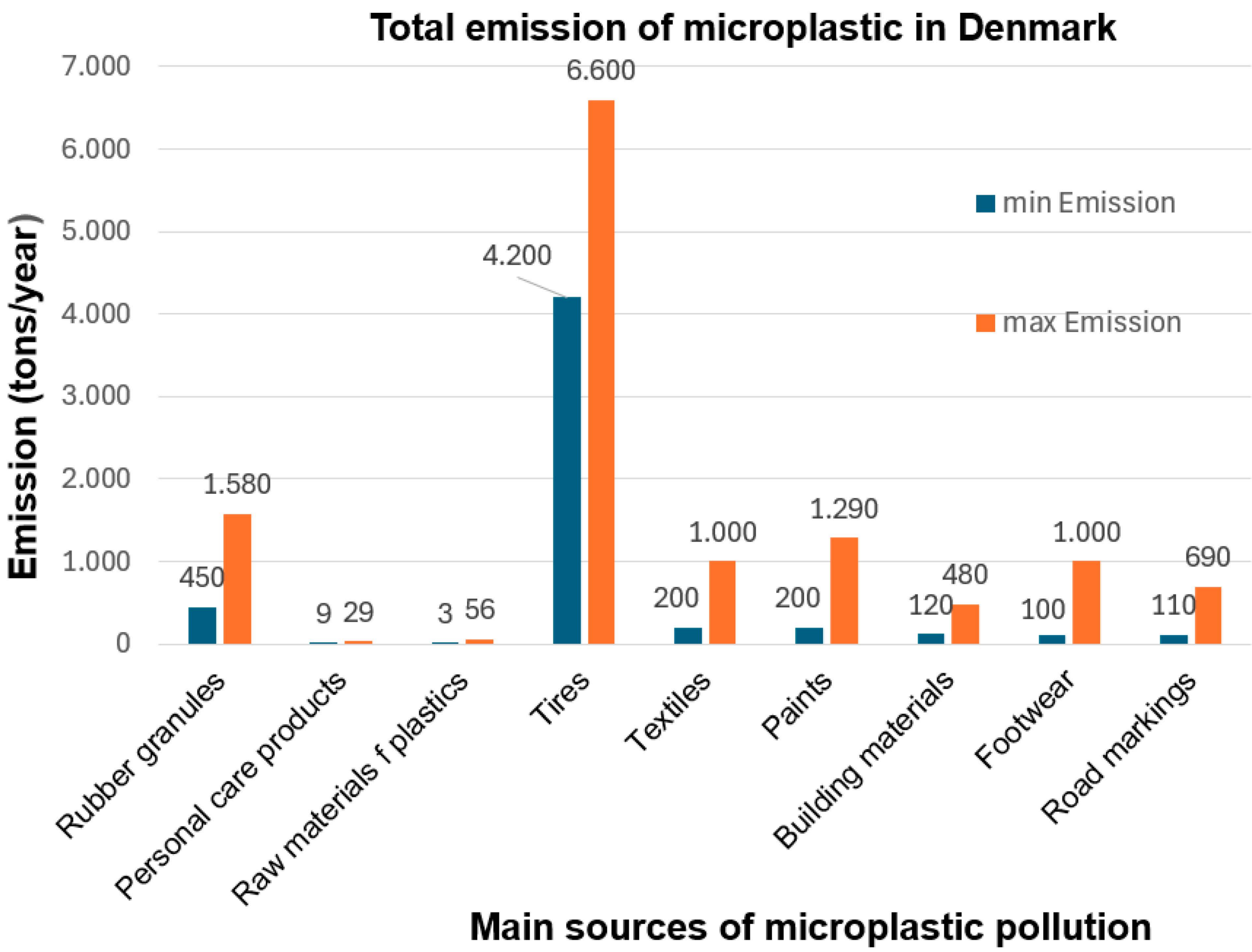
Figure 8. Data on the emission of microplastic in the EU in 2016.

In Figure 9, we illustrate the data on microplastic emission in Denmark [28–30]. As in Figure 8, we observe that car tires, paints, and textiles are the primary sources of microplastic pollution. Therefore, the total emission of microplastic to the Baltic and North Seas can be estimated to be up to 3100 tons/year.

Table 2 summarizes the numbers for various emission sources to make a better comparison.

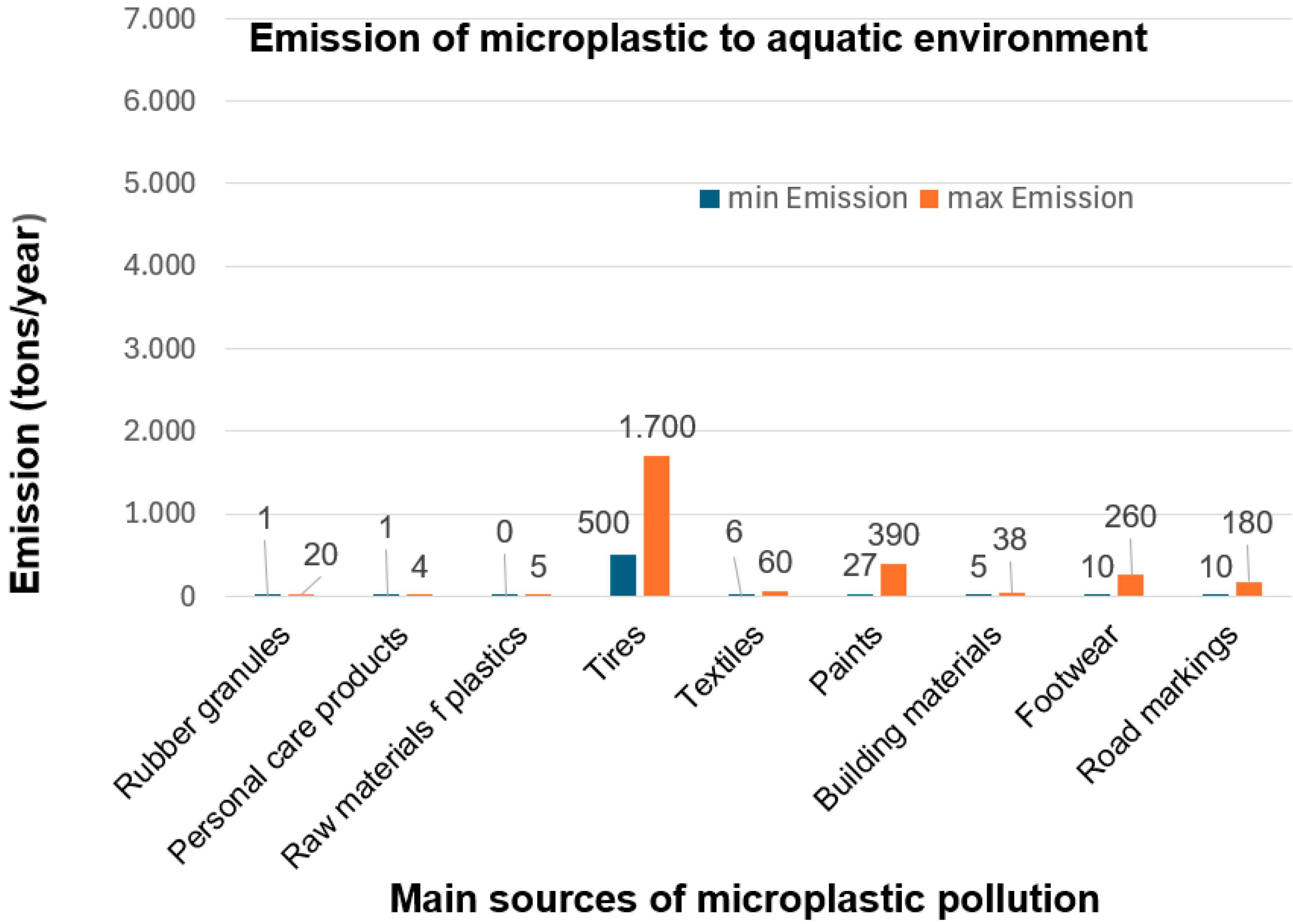
Table 2. Microplastic pollution from different sources in Denmark.

Source	Value
Car tires	Up to 1700 tons/year
Textiles	Up to 60 tons/year
Paints	Up to 390 tons/year
Wind turbines (our theoretical estimation)	1.7 tons/year



(**a**)

Figure 9. *Cont.*



(**b**)

Figure 9. Microplastic pollution in Denmark: (**a**) total emission of microplastics and (**b**) emissions to the sea.

5. Conclusions

In this article, the volume of removed plastic due to the leading-edge erosion of wind turbine blades is evaluated using different approaches. A probabilistic model of material removal due to successive rain droplet impacts was developed and applied to the determination of the volume loss of blades due to erosion. As a result, it was shown that for the case of an average tip speed of 90 m/s, 1000 mm of rain annually, and a mean rain intensity of 1 mm/h, the volume loss is at the level of 15 mm^3/cm^2 per year. For the area 10 m $\times$ 50 mm (full leading-edge surface), it leads to 75 cm^3 or 75 g per blade per year.

Another estimation is made on the basis of the blade repair statistics. Given that the blade repair frequency is known (from various surveys and databases [16,17]), and the repair is carried out at approximately the same degree of erosion (not too often, to reduce costs, but also not to seldomly, to exclude the surface defects reaching into the laminate), one can determine the volume of eroded plastic, per year, as the frequency of repairs, multiplied by the average volume of removed blade material each time the repair team arrives.

The estimated volume of eroded plastic is 30. . .540 g per year per blade. It is higher for offshore wind turbines (80. . .1000 g per year) and lower for onshore wind turbines (8. . .50 g per year). For the whole of Denmark, it is estimated to be about 1.6 tons per year, which is one order of magnitude less than footwear and road markings and three orders of magnitude less that tires. The estimations made with repair statistics correspond well to the estimations made with the probabilistic model, and also to the literature data. Additionally, the estimations made by Solberg and colleagues in [5] are analyzed, and it is demonstrated that these results are based on a wrong extrapolation and many wrong assumptions.

With a view to the wind energy development strategy, one should note the following. With increasing blade size, its erosion will become more intensive; thus, it is very important to develop new, improved leading-edge protection. While 100. . .400 g per year is not a large value, and is hundreds or thousand times less than the plastic coming from footwear and tires, there is still potential to develop better, more protective coatings [31,32]. Further, regular and efficient maintenance is also very important to avoid the situation when the surface erosion reaches the laminate. To achieve this, the blade repair costs should be reduced and the maintenance procedures optimized [32,33].

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