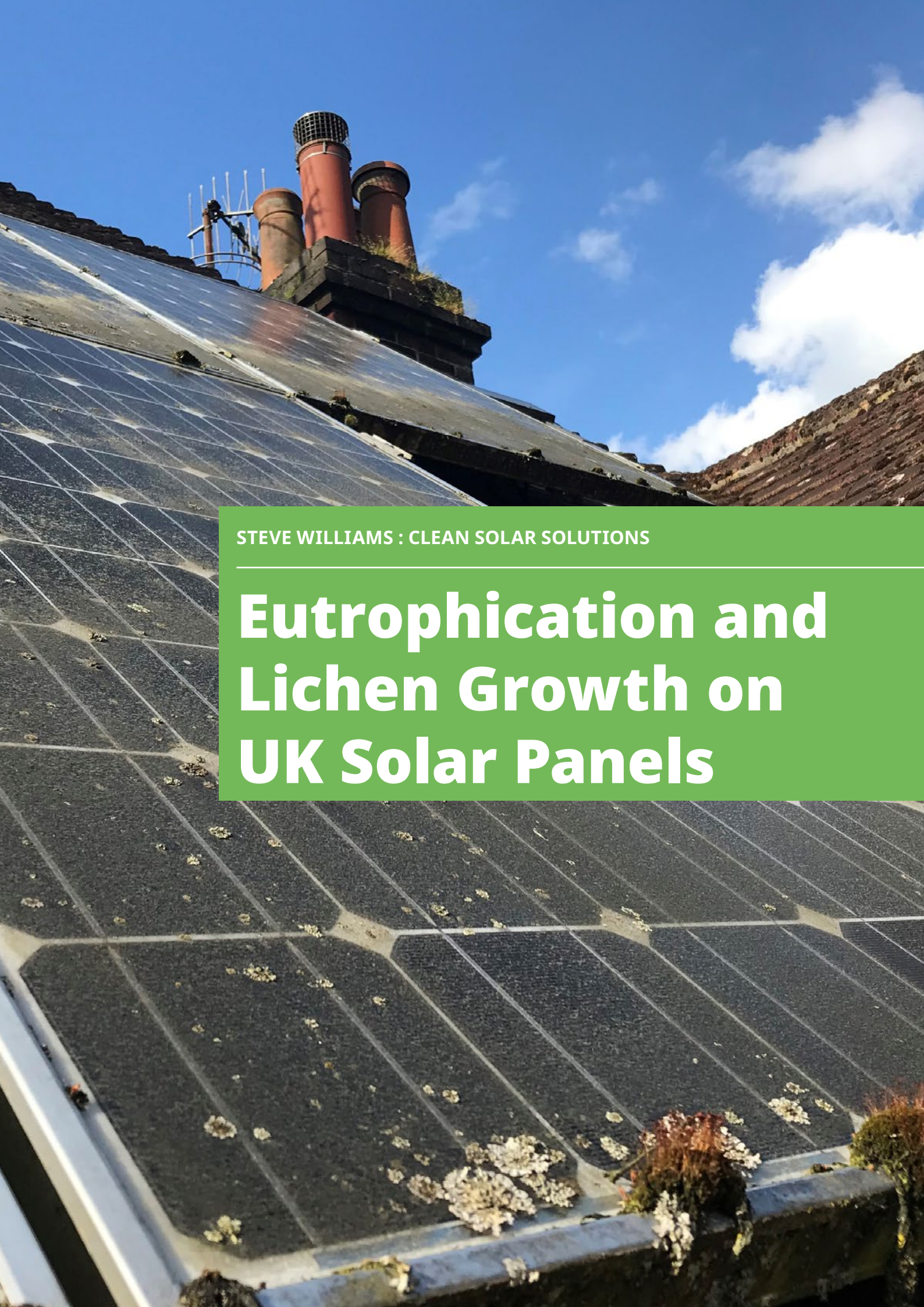

STEVE WILLIAMS : CLEAN SOLAR SOLUTIONS

Eutrophication and Lichen Growth on UK Solar Panels

Contents

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Introduction to Eutrophication and Lichen Growth on Solar Panels

Clean Solar Solutions have cleaned approximately 5 million solar panels over the last 8 years. In the first years of solar panels being installed in the UK, lichen was not a known issue. However, as solar arrays have aged, lichen growth has become a widespread issue.

It was observed that lichen growth was more frequent in some farming environments and near certain species of tree, but the reason was not known.

Steve Williams has been involved in the external property cleaning industry since 1996, running his own company. As well as this, he is now a solar panel cleaning consultant and the Managing Director of *Clean Solar Solutions*, a company he set up in 2013. He privately began photographing and researching lichen growth on solar panels in 2015. Steve then engaged in intensive lichen research from 2017 to try and find out why lichen was growing on solar panels, why it proliferated in some areas of solar farms and not in others and how the chance of lichen growth could be reduced. Over four years of observation and research is compiled and explained throughout this article.

Lichen growth on solar panels is the end result of a series of processes. Remove or reduce one of these processes and lichen will not grow on solar panels. In order to understand why lichen grows, it is essential to go further back in the organic process, beginning with understanding nitrogen, ammonia, eutrophication and the roles that these play in lichen growth.

This article endeavours to benefit the wider solar industry, by explaining why lichens grow and how lichen growth can be minimised on UK assets.

What is Eutrophication?

Eutrophication can be defined as:

> *"...an enrichment of water by nutrient salts that causes structural changes to the ecosystem such as: increased production of algae and aquatic plants..."* [1]

The cause of eutrophication can be directly linked to the water becoming supercharged with nitrate or phosphate-containing components, such as fertilisers or sewage. This eutrophication process causes an algal bloom. A similar algal bloom caused by eutrophication on solid substrata may stimulate the colonisation and growth of lichens.[2]

1 OECD (Organisation for Economic Cooperation and Development)
2 The British Lichen Society

Cultural eutrophication is the process:

> *"when man speeds up the aging process by allowing excessive amounts of nutrients in such forms as sewage, detergents, and fertilizers to enter the ecosystem"* [3]

Therefore, cultural eutrophication can be seen at water and sewage treatment plants, golf courses, fertilisers and in many farming activities. Allowing eutrophication to occur on solar panels is the first step towards lichen growth.

Within this article, the role of cultural eutrophication in increasing lichen growth on agricultural solar arrays and other sites will be thoroughly explained.

What is Lichen?

A lichen is not a single organism, but the result of a partnership (mutualistic symbiosis) between a fungus and an alga or cyanobacteria.[4] A lichen is a symbiotic partnership between a specialized fungus and a photosynthetic organism, often an alga.[5] Lichen is defined as:

> *"a simple slow-growing plant that typically forms a low crusty, leaflike, or branching growth on rocks, walls and trees."* [6]

There are three main types of lichen, crustose, foliose and fruticose with all notable differences, as shown in Figures 1, 2 & 3.

Figure 1: Crustose Lichen

Figure 2: Foliose Lichen

Figure 3: Fruticose Lichen

3 Encyclopædia Britannica
4 Australian National Botanic Gardens and Australian National Herbarium
5 The British Lichen Society
6 Collins English Dictionary

What is Nitrogen?

Nitrogen can be defined as:

> *"the chemical element of atomic number 7, a colourless, odourless unreactive gas that forms about 78% of the earth"s atmosphere."* [7]

The natural circulation of nitrogen by living organisms, also known as the nitrogen cycle,[8] is one of the Earth's biogeochemical cycles that involves the conversion of gaseous nitrogen (N_2) into different chemical compounds. The main processes of the nitrogen cycle are fixation, ammonification, nitrification, and denitrification.[9]

As one of the macronutrients, nitrogen plays an important role in plant growth.[10] Both nitrogen-fixing lichens and non-nitrogen fixing lichens absorb the nitrogen as one of the nutrients needed for growth.[11]

Nitrogen is one of the key components that can lead to eutrophication.[12]

Where Are Nitrogen Compounds Found?

Nitrogen compounds are important ingredients for many industrially important compounds such as ammonia, nitric acid, nitrates and others.[13] It is essential for agriculture and the manufacture of fertilizer. It is also, indirectly, relevant to the manufacture of all chemical compounds that contain nitrogen, which includes explosives, most pharmaceuticals, and dyes.

What is Nitrogen Fixation?

Nitrogen fixation can be defined as:

> *"a chemical process that converts atmospheric nitrogen into ammonia, which is absorbed by organisms."* [14]

Thus, meaning that nitrogen fixation is fundamentally the conversion of atmospheric nitrogen into a form that plants can more readily utilise. Atmospheric nitrogen or molecular dinitrogen (N_2) is relatively inert: it does not easily react with other chemicals to form new compounds.[15] Nitrogen fixation is essential for some forms of life. This is because nitrogen compounds are required for the biosynthesis of the basic building blocks of plants, animals and other life forms, e.g. lichen.[16]

7 Oxford Dictionaries
8 The Nitrogen Cycle: of Microbes and Men by John Arthur Harrison
9 The Nitrogen Cycle: Processes, Players and Human Impact by Anne Bernhard
10 Role of Nitrogen for Plant Growth and Development: A Review by Shah Jahan Leghari
11 Response of the nitrogen-fixing lichen *Labaria pulmonaria* to phosphorus, molybdenum, and vanadium by Jade A Marks
12 What is Eutrophication? Causes, Effects and Control by Francesca Scannone
13 Organic Nitrogen Compounds by Ed Vitz, John W. Moore
14 Maximum Yield definition
15 Nitrogenase and Nitrogen Fixation, Boundless, Libretext
16 http://reasonandscience.catsboard.com/t1562-the-nitrogen-cycle-irreducible-interdependence-and-the-origin-of-life

What is Ammonia?

Ammonia can be defined as:

> *"A colourless gas with a characteristic pungent smell, which dissolves in water to give a strongly alkaline solution."* [17]

Therefore, Ammonia is a soluble gas and is an important atmospheric pollutant. Ammonia dissolves in water and other substances in the atmosphere.[18] It then becomes ammonium (NH4+). Ammonium is found in abundance in both natural and man-made circumstances.[19]

Why Does Eutrophication Happen on Solar Panels?

The vast majority of solar panels are designed with glass that sits inside a slightly raised metal frame. Eutrophication is seen on solar panels at a micro-level, often along the bottom edge of a solar panel, where the frame of the panel stops the water running off the bottom edge of the glass.

When it rains or when there is a high relative-humidity level, water gathers along the bottom edge of a solar panel, held in place by the solar panel frame. In geographical terms, a basin is defined as:

> *"...a limited drainage basin that normally retains water and allows no outflow to other external bodies of water..."* [20]

Whereas, a geographic sink is defined as:

> *"...a depression with a basin where water collects with no visible outlet."* [21]

For the purpose of this article, the solar panel frame can be characterised as the basin and the area along the bottom edge of a solar panel where water gathers can rightfully characterise as the sink. When water in the sink draws in fertiliser or other nitrogen-rich material, it becomes enriched and will start the process of eutrophication, causing the growth of algae. As solar panels are south-facing, they have high levels of light, causing the photosynthesis process to start. This process will often happen daily from dew on solar panels or can happen multiple times during the day from rain showers, mixed with sunny spells. This creates the perfect atmosphere

17 Oxford Dictionaries
18 National Centre for Biotechnology Information/Ammonia
19 The Nitrogen Cycle: Processes, Players and Human Impact by Anne Bernhard
20 Climate Change Science, A Modern Synthesis, Volume 1 - The Physical Climate by CTI Reviews
21 Foundations of Earth Science by CTI Reviews

in the sink for the algae to grow. This is very commonly observed on solar panels with a green line along the bottom edge, as seen in Figure 4.

When algae grow in the sink, it is easy for it to spread across the whole basin area. In many cases, this facilitates a suitable partner to which lichen can attach in order to grow. It is possible for algae to grow without a partner. However, this is rare.

During our research it was evident that the likelihood of eutrophication and lichen growth increases exponentially when the angle of the solar panel is shallow. This is because shallow panels hold more water in the sink, more nutrients accumulate and algal and lichen growth will start more quickly and spread to a wider area, as seen in Figure 5.

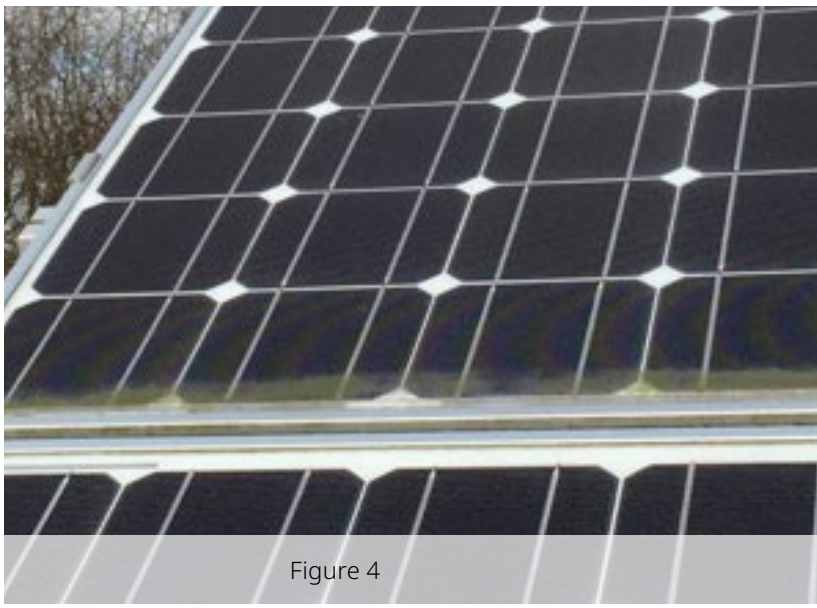
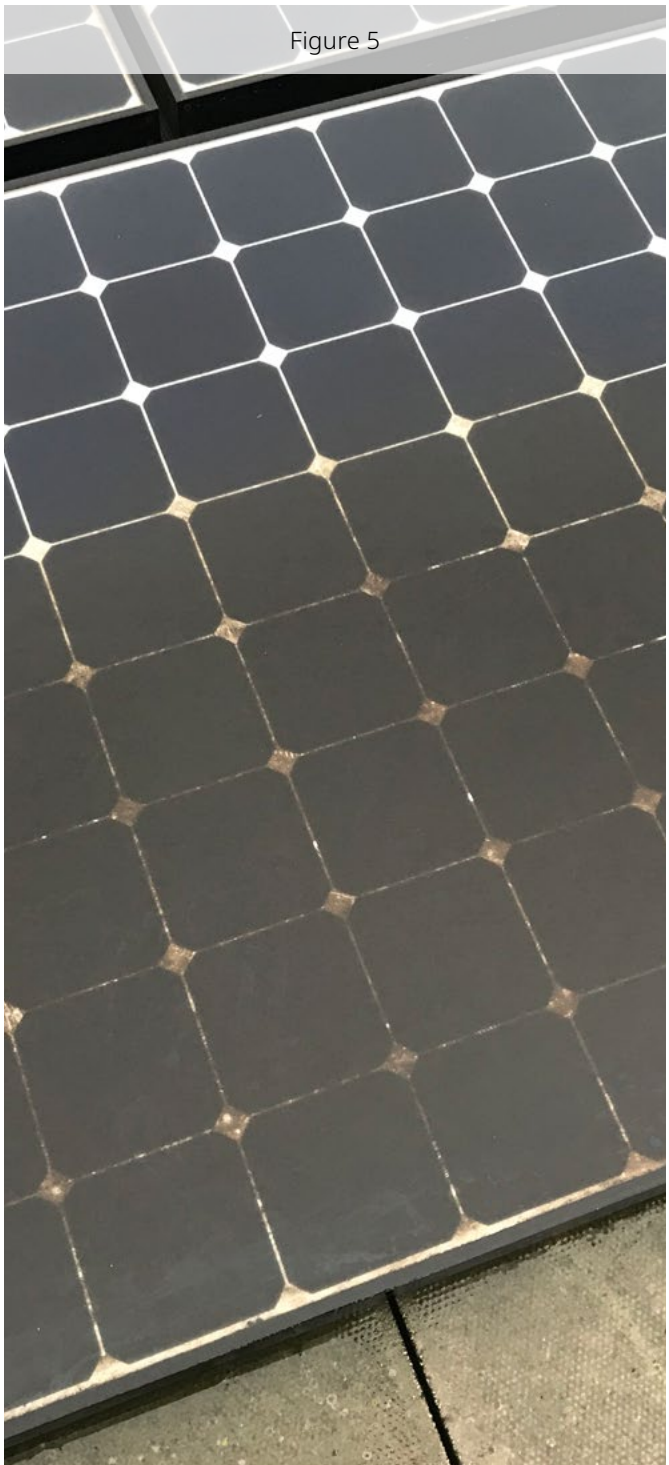


Figure 4

Figure 5



Lichen Characteristics

A lichen is not a single organism, but the result of a partnership (mutualistic symbiosis) of two or more different life-forms in a thallus. A thallus can be described as:

> *"The part of a lichen that is not involved in reproduction, the 'body' or 'vegetative tissue' of a lichen"* [22]

The thallus is made up of filaments of the fungus called *hyphae*. Some lichens are epiphytic, meaning that they are an organism that grows on the surface of a plant.[23] Most epiphytic lichens grow on bark (corticolous). Lichens which are most commonly found on bark may also colonise stone and similar "mineral" substrata including glass, aluminium etc.[24] Other lichens are vitricolous lichens, which are lichens that grow on glass.[25] Lichens do not only need nutrient-rich substrata in order to thrive:

> *"Lichens effectively trap airborne particulate matter"* [26]

As a consequence, some lichens may be able to fix nitrogen, and all lichens may be able to absorb gaseous nitrogen compounds from the air, along with airborne particles of nitrogen-rich fertiliser from farming or other activities.

Whereas many fungal species derive their nutrition by breaking down dead organic matter, the energy source of the lichen fungus is the photosynthetic products of its partner.[27] Lichens grow on various substrata; those growing on plants are called epiphytic, though the term corticolous is usually used for those which grow on the bark of trees and shrubs.[28]

The term saxicolous is defined as "living on or among rock",[29] meaning saxicolous lichen is found growing on rocky substrata. This is also the term that would be used for lichens growing on solar panels. Most of the lichen species growing on solar panels seem to have a green alga as their photosynthetic partner and many of the species involved are also symbiosis commonly found on twigs and branches.[30]

Types most commonly found on solar panels are crustose and foliose lichen, as shown previously. *Physcia adscendens* and *physcia tenella*[31] appear to be the dominants on solar panels in the UK. Crustose lichens are most tolerant to atmospheric change, so are most hardy.

22 United States Department of Agriculture, Lichen Biology
23 Australian National Botanic Gardens, Australian Lichens
24 Lichens to Biomonitor the Environment by Vertika Shukla, Upreti D K, Rajesh Bajpai
25 Australian National Botanic Gardens, Australian Lichens
26 Monitoring with Lichens - Monitoring Lichens, edited by Per Luigi Nimis, Christoph Scheidegger and Patrica A Wolseley
27 Utah State University, Department of Biology, Intermountain Herbarium, Lichen
28 Distribution of Corticolous Noncrustose Lichens on Trunks of Rocky Mountain Junipers in Boulder County, Colorado, Janet L Peard *The Bryologist*, Vol 86, No 3 (Autumn, 1983) p 244
29 Collins Dictionary
30 Woodland Trust, Trees, Woods and Wildlife, Plant and Fungi, Lichens
31 The British Lichen Society

Crustose lichens have the smallest surface area to volume ratio and this may be one of the reasons why many crustose species appear to be more tolerant of atmospheric changes.[32]

How Do Lichens Grow?

Due to the absence of a protective cuticle (skin), many, but not all lichens readily absorb precipitation of any *Ph* making them highly susceptible.[33] Therefore, they are very susceptible to the atmosphere around them, be that air, humidity levels and light conditions. All lichens require periods of high relative humidity since they often obtain their required nutrients, water and air directly from the atmosphere.[34] They can thrive or die, depending on these local factors.

Relative humidity is one of the factors affecting the distribution of lichen. The wetting and drying cycle is thought to be important in giving lichens a competitive advantage. A higher level of water facilitates the spread of lichen growths easier. Areas around trees have a naturally higher relative humidity value, encouraging further lichen growth.[35]

The British Lichen Society's research states:

> *"Lichens absorb water from the atmosphere, but unlike plants they have no means of keeping water within the lichen during dry spells. Water content can fall to 15-30% and the lichen is then metabolically inactive."* [36]

Thus, meaning the lichen dries up and becomes very brittle. It remains in stasis. Lichen pieces can break away and when they become wet again, they quickly absorb the water, become soft and fleshy and the detached pieces can form new lichens.

As soon as humidity levels rise on a lichen, the thallus absorbs water and when there is sufficient light, photosynthesis re-starts within minutes. Lichen distribution can also be influenced by the occurrence of fog, which provide lichens with moisture and extend their growing season into rainless periods.[37]

The photosynthetic partner within lichen can then use the water and carbon dioxide in the air and undergo photosynthesis, resulting in growth. Temperature and growth of lichens are not correlated, as proved in research by Macfarlane & Kershaw in 1978:

> *"Lichens are believed to be extremely resistant to high-temperature stress when desiccated. Results from a re-examination of this concept indicate that some air-dry lichen thalli can be extremely sensitive to even moderate levels of heat stress whereas others exhibit a considerable degree of heat resistance. These differential levels of thermal resistance correlate exactly with the ecology of these populations."*[38]

32 Geomorphological changes with a Hillslope caused by a windthrow event in the Tatra Mountains, southern Poland by Dariusz Strzyzowski, Geografiska Annaler: Series A, Physical Geography, p 347
33 Air Pollution Information System, Acid Deposition: Coniferous Woodland
34 The British Lichen Society
35 Factors Affecting the Growth of Lichens by Tai Tong and Hung Shui Kiu
36 The British Lichen Society
37 Lichen Thermal Sensitivities, Moisture interception and elemental accumulation in and around South African ecosystem by Khumbudzo Walter Maphangwa
38 Thermal Sensitivity in Lichens by D Macfarlane and A Kershaw, 1978, p 739

Therefore, suggesting that many lichens can tolerate extremes of temperature and during periods of drought their growth temporarily ceases.

Why Do Lichens Grow?

Lichens reproduce using either sexual reproduction or vegetative reproduction. With sexual reproduction, when a new lichen spore germinates, it quickly needs to find a suitable species of alga to live off so that it can become a young lichen. This can be an alga living independently or an alga within another lichen thallus and it will envelop this and live alongside another lichen thallus.[39]

Lichen absorbs nutrients that it needs from rainwater and dust. Bird droppings are also rich in nitrogen. Solar panels are exposed to the elements and in the UK, have an abundance of dust, rainwater and often bird droppings. Birds frequently perch along the top edge of solar panels and deposit their droppings along the top edge of the panel, as seen in Figure 6. This is the uncropped view of Figure 4. Take note of the top left corner.

With the nitrogen-rich bird droppings being at the top of the panel, when it rains, remnants of bird droppings get broken down and dissolved and run down the basin and gather and mix with the rainwater and other dust in the sink. With algal growth very likely already present in the sink and lower part of the basin, the conditions on this solar panel are ripe for lichen growth.

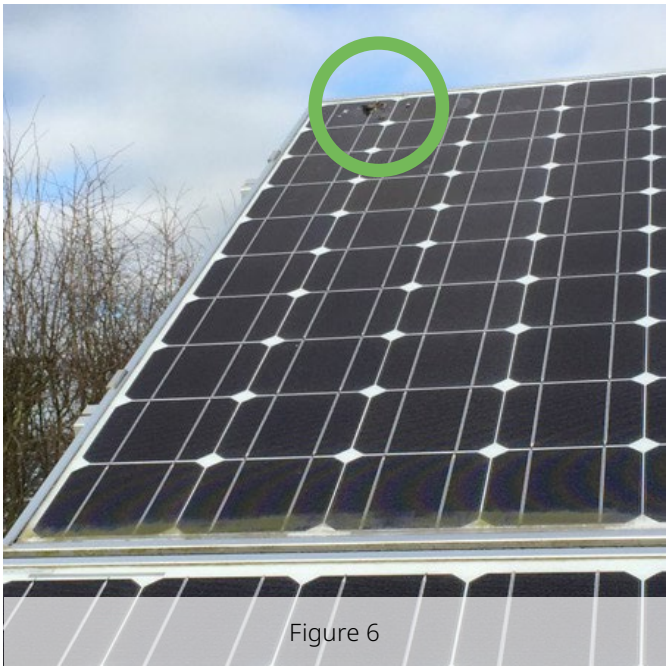


Figure 6

Types of Lichen Found on Solar Panels

The main types of lichen observed throughout our research on solar panels in the UK, are a foliose lichen and various crustose lichens. The exact species of all these lichens, this study has not yet been able to ascertain.

Foliose lichen is easier to remove from solar panels, as it is softer in nature than crustose lichen and does not attach to the solar panel in an aggressive way. In general, it seems foliose lichens grow where the glass of the solar panel adjoins the frame of the solar panel.

Crustose can be defined as:

> *"a habit of some types of algae and lichens in which the plant grows tightly appressed to a substrate, forming a biological layer of the adhering organism"* [40]

39 Lichens, Last Dragon Lichen Thallus Types
40 Biology 1110-1120 LAB MANUAL Edition 2nd 12

Crustose lichen adheres very closely to the substrates at all points and is commonly found on rough surfaces such as rocks and tree bark. Crustose organisms can be detrimental to engineered structures when found on buildings, coastal structures, and ships, so we feel it is important to remove it from solar panels too, for structural reasons as well as electrical output reasons.

How Do Lichens Attach to Solar Panels?

Lichens use various methods of attachment. Many foliose species possess rhizines which help anchor the thallus.[41] Rhizines are not analogous to roots since they do not contain vascular canals and any limited uptake of water is by capillary action. Most of the water and inorganic nutrients absorbed by the lichen are thought to be absorbed directly by the thallus. The ability of many lichen species to readily absorb water from the environment makes those species susceptible to atmospheric pollution. Lichens are also sensitive to light levels, many species favouring well-lit conditions.

When growing on the bark of trees, the attachment of lichens may be aided by the roughness of the surface. The surface of standard glass is much smoother than tree bark, and substances secreted by the hyphae may act as a type of "glue".

Applying this research to the topic of this article, lichen appear to grow in a symbiotic relationship with green algae and there are strong patterns to show that green algae is a pre-cursor to lichen colonisation. However, solar panel glass in crystalline solar panels is not standard glass, it has a rough surface. It is designed with a rough surface in order to make the EVA film bond well to the surface during the lamination process. It is also rough on the outside so that as much light as possible is channelled into the cells underneath the glass and improve the efficiency of the panel. Lichen is very difficult to remove from solar panel glass because the strong hyphae appear to attach into the microscopic pits within solar panel glass and the growth remains relatively flat.

What Role Do Quercus Trees Play in Lichen Growth?

Throughout the course of this research, English or Common oak trees (*Quercus robur*) are frequently found around the edges of solar farms and in places, even within a solar farm where lichen was found.

Quercus trees contain organic nitrogen.[42] Wet deposition of nitrogen on to solar panels occurs when it rains. The dense canopy of *Quercus* trees may be effective at intercepting particles, including those containing nitrogen compounds.

The presence of perching birds and other animal activity (including invertebrates such as aphids) will generate nutrient-rich droppings, frass and honeydew.[43] These may be mobilised by rain and nitrogen rich rainwater when it is deposited on solar panels. The honeydew from aphids, if this rained down on to solar panels, would likely be very effective at promoting

41 The Microbial World: Lichens by Jim Deacon, Institute of Cell and Molecular Biology, The University of Edinburgh
42 Nitrogen resorption in leaves of tree and shrub seedlings in response to increasing soil fertility by P Singh, K Bargali and A Joshi, Vol 89, p 396
43 Insect canopy herbivory and frass deposition affect soil nutrient dynamics and export in oak mesocosms by Christopher J Frost & Mark D Hunter. Ecology (2004) 85. 3335-3347

alga and also lichen formation, making the surface of the glass "sticky" (similar to parking a car under certain tree species during the summer).

It was observed that there is a clear increase in lichen growth on solar panels where *Quercus* trees are present. Other tree species do not seem to increase the level of lichen growth to any where near the same levels as when *Quercus* are nearby. We are initially attributing this to the increase in nitrogen, combined with the increased humidity around trees, creating ideal lichen growth conditions.

Case Study

Clean Solar Solutions have cleaned the solar panels on a Derbyshire solar farm since 2013. This was initially done on a six-monthly basis and the panels in one particular zone were consistently dirtier than the panels across the other zones. The reason was quickly apparent. It was the only part of the solar farm which was lined by trees.

At the point of their starting to document their cleaning by way of photographs on each clean, lichen grown on solar panels was not a known issue, nor had it been observed. Cleaning the solar panels six-monthly on this site kept the lichen at bay. Algae was always noticed as being present in one zone, but this was easily removed during the cleaning process.

For various third party reasons, the solar panels were not cleaned for 12 months. The results on the tree-lined zone were devastating from a production point of view. It was noticed by the site owners that this part of the site was not generating as much electricity as the rest of the site by comparison, so a clean was implemented.

Clean Solar Solutions staff had cleaned this site 5 times previously, so knew the site well. However, they were surprised by the condition of the solar panels in the tree-lined zone. Many had become covered in lichen.

Upon further investigation, it was noted that the closer the panels were to the trees, the more algae had accumulated on the panels. But even more noteworthy, was that the panels closest to the trees had become covered in lichen.

This event triggered the investigation and research into why algae and lichen grows on solar panels.

The following series of images from a single solar farm taken over a period of time show the effect of not cleaning the panels near the trees for just 18 months when *Quercus* trees are nearby.

Figure 7 Showing the Quercus trees in the background.

Figure 8 light algae growth on the solar panels.

Figure 9 severe algae growth on the whole of a solar panel.

Figure 10 a solar panel adjacent to the Quercus tress clearly shows thousands of lichen growths.

Figure 11 Close-up of the lichen thallus.

Figure 12 The solar panels after Clean Solar Solutions had removed the lichen. The lower corner panel on this image is the same as *Figure 9.*

Figure 7: February 2015

Figure 10: October 2016

Figure 8: October 2016

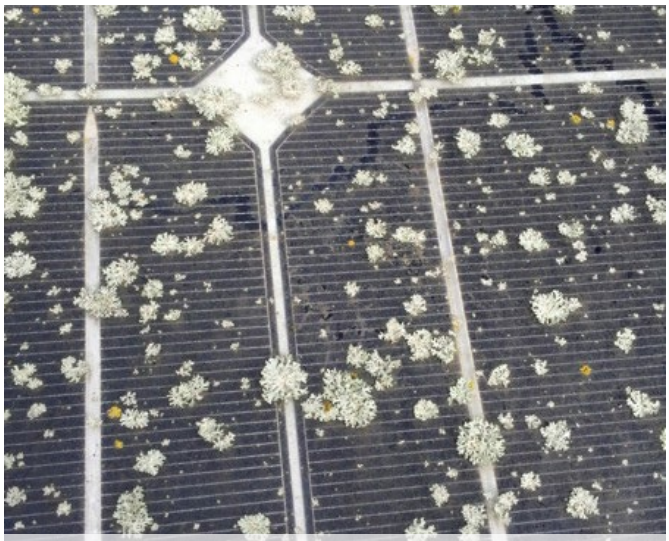


Figure 11: October 2016

Figure 9: October 2016

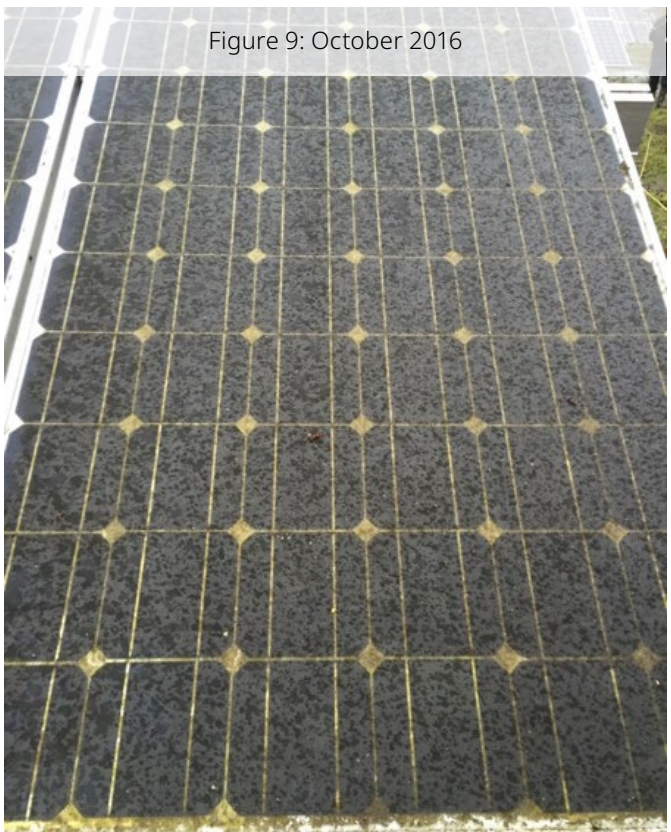


Figure 12: October 2016

What Role Does Ammonia Play on Lichen Growth?

Rainwater is able to capture ammonia as it falls.[44] It can readily be deposited on soils and plants and the research shows that it contributes to lichen growth on solar panels by falling ammonium deposits being left on *Quercus robur* trees. This can then be deposited on solar panels by throughfall, the process of rainwater falling through a tree canopy and onto the surface below and contribute to lichen growth.

Atmospheric ammonia (NH3) affects growth of epiphytic vegetation, such as lichen. High concentrations of NH3 causes a dominance of nitrophytic lichen species. Ammonia is very soluble in water and readily reacts with other substances in the atmosphere to form ammonium (NH4+). NH4+ causes an increased availability of nitrogen and where there is more nitrogen available, there is more lichen.

Although the greatest concentrations of ammonium-N in rain are found in the south and east of the UK, the deposition of ammonium-N in rain is largest in the north and west, because of greater rainfall. Ammonia compounds can be transported in the atmosphere over long distances. Some of the ammonia deposited in the UK comes from emission sources outside the UK.

There seems to be a strong correlation between the presence of ammonia near solar panels and lichen growth. We have noticed increased rates of growth of lichen on dairy, poultry and grain stores. The rate of lichen growth that we have seen in farming environments is in-line with the source of ammonia, as seen in the chart here.

44 Rainwater Chemistry Across the United States by Ellen Root, Whit Jones, Bessie Schwarz, Jack Gibbons, Bereket Haileab, Advisor November 22, 2004

Lichen Growth on Solar Panels in an Agricultural Setting

Lichens growing on solar panels on or near farms can absorb nitrogen during the crop spraying process on farms. This can be via liquid from overspray carried along in the wind or in gaseous from. Crop spraying on nearby or adjacent farms can therefore trigger and accelerate the lichen growing process.

Areas of solar farms with overhanging trees create a higher relative humidity value in that area and increase the rate of lichen growth.

The most favourable light intensity for lichen growth is around 150 lux. This is why lichens are more prevalent in shaded areas, where light intensity is low.[45] Solar panels are obviously placed in areas with the most potential for high light intensity. However, some solar panels are located in the direct shade of trees, nearby trees or under the canopy of trees, even though that tree may never cast its shadow on the solar panels below.

Because lichens absorb moisture and nutrients from the atmosphere, they are very susceptible to air pollutants and these accumulate within the lichen. Major pollutants that kill certain sensitive lichen include nitrogen compounds and sulphur dioxide, both of which can be found in road traffic pollution from exhaust emissions.[46]

Foliose lichens are extremely sensitive to sulphur dioxide, which is a by-product of air pollution, particularly traffic pollution. Sulphur dioxide reacts with the chlorophyll in lichen, causing a decrease in the respiration of the lichen.[47] This decrease will cause the lichen to die. However, sulphur dioxide levels across most of Great Britain are now well below the limiting level for the growth of almost all lichen species.

Lichen Growth on Dairy Farms

It has been our finding that there is a substantial increase in lichen growth where there are high levels of ammonia, such as on dairy farms. It has been determined that:

> *"Cattle farming produces 44% of the UK"s total ammonia emissions. Most of the ammonia losses are from manure spreading on land (48% of cattle emissions) and from livestock housing (34% of cattle emissions)."* [48]

In the case of solar panels mounted on dairy sheds, there will be an increase of NH_3, due to urine, excreta, manure held in storage and volatilization during the manure spreading process. This volatilization process can also explain why lichen can be found on solar farms adjacent to fields where manure is spread to aid crop growth.

Urine deposited in and around buildings, on concrete or other solid surfaces, cannot be

45 Factors affecting the growth of lichens by Tai Tong and Hung Shui Kiu
46 Air Pollution Information System, impacts air pollutions lichens and bryophytes mosses and liverworts
47 Biological Journal of the Linnean Society, Vol 115 Issue 3, 1 July 2015, pp 611-635
48 Ammonia in the UK, Defra

absorbed. Instead, it mixes with dung that contains urease, so the urea is rapidly broken down to release ammonia.

In cooler climates such as the U.K., cattle are often kept in sheds over winter and the manure stored until spring. This will result in increased levels of NH_3, which aids lichen growth.

Cattle housing tend to be ventilated naturally through gaps in the walls and roof. However, for loose-housed cattle, those kept in sheds with a deep layer of straw bedding covering the whole floor area, using more straw may reduce ammonia emissions from the building. The straw absorbs the ammonia, which means there will not be any increase in emissions from manure storage or spreading.

Lichen Growth on Solar Panels on Poultry Farms

Poultry farming produce less ammonia emissions than that of cattle farming with a total of "14% of the UK's total ammonia emissions".[49] Just under half of the emissions from poultry production come from housing, with the same amount coming from manure spreading.

Poultry excrete uric acid, not urea. Under moist conditions, uric acid is quickly broken down to urea, and the ammonia within the urea may then volatilize as described above. Ammonia emissions from poultry buildings, therefore, depend greatly on whether the excreta are kept wet or dry.

Lichen Growth on Solar Panels Near Land Where Fertiliser is Spread

Using N-containing fertilizers on land produces around 9% of the UK's total ammonia emissions. Fertiliser can be carried some distance in the air, so it is very possible for fertiliser to be spread on one field and the overspray be carried in the wind to a nearby solar farm. This solar farm may have no lichen contributing factors in its immediate vicinity, but the airborne fertilizer can still cause lichen growth on a site.

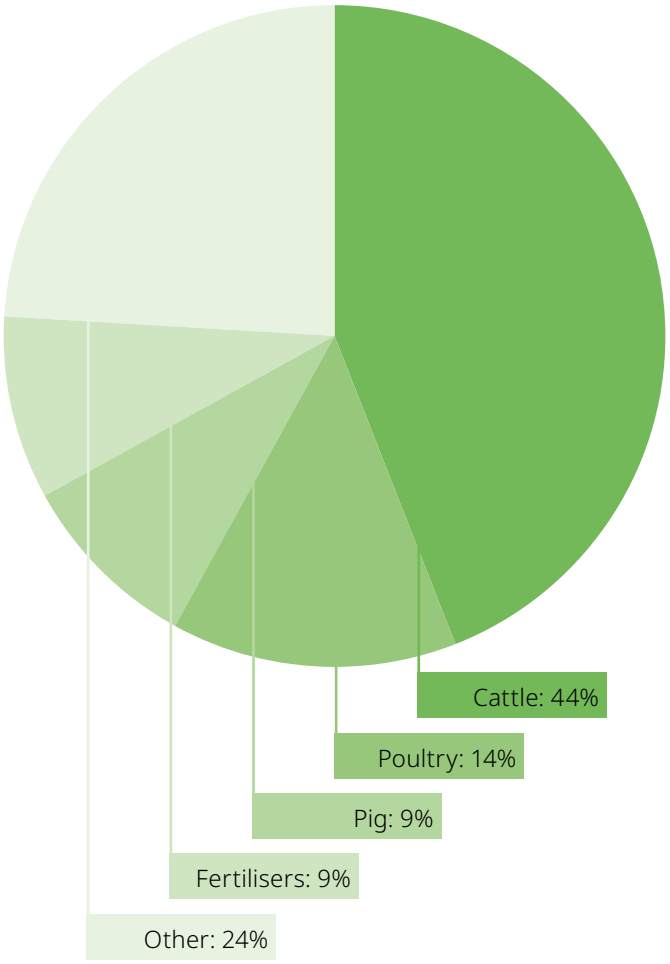


Figure 13: UK's Total Ammonia Emissions

49 Ammonia in the UK, Defra

Can Lichen Damage a Solar Array?

Lichen growths can be deeply damaging to a solar array, often creating hundreds of individual hotspots on a single module. Each individual thallus can grow up to 27mm in one year, depending on its species. This will cause a decrease in the output of a solar module. In certain conditions, lichen can be found on thousands of modules on a single site.

Water can even gather on the sides of solar panel glass, due to the viscosity of water and its ability to cling to surfaces. This is why we see accelerated lichen growth observed on solar panel frame edges, demonstrated on the right side of the picture below.

Removing Lichen from Solar Panels

Because lichens are brittle when dry, they can break off into very small pieces. Each of these very small pieces can form its own thallus and in turn, a new lichen growth. Trying to remove lichen from solar panels in a dry, high-summer is not advised for this reason.

The process of lichen removal should be attempted by a solar panel cleaning company with knowledge of both the equipment they are working on and knowledge of the lichen that they are trying to remove. A chemical removal will be needed in many cases, using equipment to remove the lichen that will not damage the panels or scratch the glass.

Clean Solar Solutions Stage Classification of Lichen Growth

Stage 1 Minimal lichen growth which can be removed from solar panels with standard solar panel cleaning equipment.

Stage 2 Lichen growth that requires chemical intervention and where we are confident that >90% of the lichen can be removed from the panels.

Stage 3 is a more problematic lichen bloom where chemical intervention is needed, but we are not able to guarantee to remove all of the lichen.

Stage 4 requires solar panels to be removed from their mounting rails, whether at roof or ground level and have the lichen removed manually at ground level.

Preventative Measures for Lichen Growth

System Design The majority of utility-scale solar farms in the UK have solar panels that are mounted 2-high in portrait or 4-high in landscape. Solar arrays that have landscape layouts, by their very design are *twice as likely* to form algae and lichen, due to there being twice as many sinks. Designing the solar farm so that the solar panels are mounted in a diamond formation instead of landscape or portrait would hugely reduce the chance of lichen growth because, while the same amount of water is running down the basin when it rains, hardly any water will gather along the bottom edge because the sink on the solar panels will be minute. Less water will therefore accumulate, reducing the risk of eutrophication.

Investing In Regular Cleaning Our extensive cleaning experience and study of lichens lead us strongly to the conclusion that without algae, lichen cannot grow easily on solar panels. For solar panel cleaning companies, removing

algae is not a problem. It can be relatively straightforward to do. However, removing lichen requires a chemical intervention and is labour-intensive. This leads to a costly cleaning bill. Investing in regular cleaning of the solar panels will keep algal growth to a minimum and hugely reduce the chance of lichen growth. A forward-thinking approach to cleaning would be to identify whole sites or parts of sites that are particularly susceptible to lichen growth and increase the frequency of cleaning on these areas. Increased cleaning may not be necessary on whole sites that only have "zones" that have lichen growth. This will make the investment in cleaning more worthwhile.

Solar Panels On Livestock Sites If solar panels are to be installed on a farm roof, it would be advisable to consult with the Farm Emissions Model (FEM) or UK equivalent. The FEM tracks the flow of nitrogen through each stage of the manure management process: feeding, housing, storage, application and grazing. If high levels of ammonia are likely to be present on site, frequent cleaning of the solar panels should be part of the Operations & Maintenance (O&M) Plan.

Ground Preparation On cattle sheds, increased use of straw covering solid or concrete floors will help reduce ammonia emissions and reduce lichen growth.

Remedial Measures for Existing Lichen Growth on Solar Panels

Removal of lichen from solar modules is a specialist process, which can often be expensive to carry out. It is, however, more cost-effective than replacing solar panels. When timed, the cleaning process of removing the lichen from the solar panel as seen in Figure 9 to its finished condition in Figure 12 takes, on average, 32 times longer than manually cleaning a solar panel without lichen growth. Clean Solar Solutions have a cleaning pre-treatment that has been approved by multiple solar panel manufacturers for lichen removal. This reduces the cleaning time from 32 times to on average, 8 times as long as manually cleaning a panel without lichen growth.

Below are factors that should be taken into consideration by asset owners or O&M companies when assessing the removal of lichen growth. This depends on the level of lichen growth on the panels.

1. Manual removal of lichen whilst solar panels are in situ.
2. Chemical removal of lichen.
3. Removal of panels from mounting rails and manual removal of lichen at ground level if the panels are too far away from the person cleaning, in order to get the pressure needed in the brush to remove the lichen.
4. Robotic cleaning should be considered on arrays, as this may give a better quality clean when compared with manual cleaning. A cleaning robot may remove the bulk of the lichen growths, leaving spot cleaning to be done manually. Each site is different in design and will experience differing levels of lichen growth. The lichen growth removal process should be tailored for each site and the cleaning company should have a range of cleaning options at their disposal.

Planning Phases of Solar Array Design

When designing any solar array on the ground or roof, attention should be given to local environmental conditions in order to ascertain

the contributing factors for the lichen growth. A site survey by an experienced solar panel cleaning consultant should be considered in order to provide reporting regarding the risk for algae, lichen growth and other soiling based on local environmental conditions and system design.

This forward planning will avoid noticeable issues such as unexpected algae and lichen growth due to nearby farming activities, proximity of nitrogen-rich environments and other soiling issues.

It is frequently noted that roof mounted arrays do not have adequate safety systems in place for cleaning. The site survey should aid the system designers in regard to safely accessing the panels for future cleaning and maintenance also. This will assist O&M companies in budgeting future cleaning and maintenance costs.

Next Stages of Clean Solar Solutions Lichen Research

1. Lichen species identification and U.K. distribution.
2. Measure light levels in "Lux" on solar farms, both in open ground and under Quercus robur trees.
3. Ascertain correlation between atmospheric conditions on each UK solar farm where lichen is present and look to take action to combat the lichen growth.
4. Complete lichen research in other countries and assess growth on solar panels.

Conclusion

The research has proved to a reasonable degree our initial observations about eutrophication and lichen growth on solar panels.

It was initially noticed that lichen only grew on solar panels where algae was visibly present, but over time, it was noted that algal growth could be at a minimum and lichen would still start to grow. It was suspected that there was a link between oak trees near solar panels and lichen growth. It was also suspected that there was a link between livestock buildings and lichen growth. It was documented that lichen growth was worst on dairy buildings, followed by poultry buildings, but was also developing on ground mounted solar farms. During the course of this research, the following conclusions were reached:

- Lichens are a symbiotic partnership and the lichens growing on solar panels require a green algal partner. This may not be visible to the naked eye but algae may be growing at a microscopic level. Microscopic algal growth is still enough for lichen to use it as a symbiotic partner and start to grow
- Lichen growth is accelerated by the presence of nitrogen and ammonia
- Livestock farms have an inherently ammonia-rich atmosphere, contributing to accelerated lichen growth. There is a direct link between farming activities and lichen growth
- There are definite risk levels of lichen growth according to the environmental activities, both natural and man-made, near to the solar panels
- Ground mount solar farms where no livestock is present are still at risk from lichen growth from nearby farming activities and nitrogen-rich fertilisers being sprayed in nearby fields
- The volatilisation process means that ammonia can be carried in the wind for some distance and settle on solar panels, contributing to lichen growth
- Regular cleaning minimises greatly the risk of lichen growth on solar panels. Each cleaning schedule should be bespoke according to the needs of each site, not portfolio-wide or by blanket terms imposed by an O&M contract
- Removing existing lichen from solar panels is labour-intensive and may require chemical intervention with a cleaning fluid approved by the solar panel manufacturer
- Site surveys and reports completed by a solar panel cleaning consultant will highlight potential soiling issues on ground and roof mounted arrays and will aid both in regard to system design and on-going cleaning and maintenance access and costs

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