Dear Ms Wilson

I wish to make some comments concerning the adverse health effects of industrial wind turbines on rural dwellers. I attach an extensive review of such health effects which I published in a Special Issue on Human Rights and Social Justice in the Journal of Social Science in 2017. Admittedly, this may seem a little out of date, but, essentially, nothing has changed since, and my conclusions remain valid.

As I set out in my 2017 paper, the problems associated with Infrasound and low frequency noise (ILFN) have been known about for over 40 years, and the Russians established safe upper limits for Infrasound in 1973. When the UK Government committed itself to wind energy in 2003 there was already a report on the problem of ILFN and how it should be measured, but this didn't suit the political mood so a new report was commissioned which appeared three months later. This dismissed the problem of ILFN and recommended measurement techniques which ignored it. This report referred to a 1996 Report (ETSU-R97) which related to wind turbines of 32 metres in height which were extant at that time – the ones extant today are many times larger, and it is known that the bigger the turbines, the more ILFN they emit. The current setback distances permitted from dwellings is woefully inadequate to protect their occupiers, despite good evidence from Finland that the ILFN effects are apparent up to 15 kms away.

Since my 2017 review there have been a number of influential papers published. One aspect which has been repeatedly confirmed is the importance of an adequate night's sleep to health. The presence of industrial wind farms in quiet rural areas is guaranteed to disrupt sleep, in a sizeable minority of people at least. The main price paid is in terms of cardiovascular disease. A recent editorial in the British Medical Journal warned, in the strongest terms, that regularly sleeping less than seven hours a night is a disaster for our mental and physical wellbeing. It continued: "As a culture, we in rich countries are in the throes of what Culpin calls "an epidemic of sleeplessness," increasing our risk of depression, anxiety, dementia, stroke, heart disease, obesity, cancer, diabetes, and road traffic crashes."

Moreover, another recent paper observed: "Observational and translational studies indicate that especially night-time noise increases levels of stress hormones and vascular oxidative stress, which may lead to endothelial dysfunction and arterial hypertension." There has also been a slew of publications lately relating environmental noise pollution to accelerated atherosclerosis in humans and sleep disruption induces DNA damage in humans and rats.

There is also a report from the USA that Suicides might be increased by 2% when wind farms are nearby, although the confidence intervals of this estimate are wide, and therefore it could be discounted. Even so, if there were any deaths at all from food poisoning in the catchment area of a restaurant, Public Health would take them very seriously indeed. If the increase is true, is it due to the direct effects of wind turbine ILFN, or is it because of the stress being inflicted on rural communities? The harm being currently inflicted on rural community relations by the Irish State's Wind Energy is extremely serious. Neighbours standing to gain financially from their erection are set against the majority who will not, and moreover, will bear the brunt of the negative health effects. Australia's Administrative Appeals Tribunal (AAT) has declared that the "noise annoyance" caused by wind turbine generated low-frequency noise and infrasound "is a plausible pathway to disease" based on the "established association between noise annoyance and some diseases, including hypertension and cardiovascular disease, possibly mediated in part by disturbed sleep and/or psychological stress/distress". The AAT also held that "The dB(A) weighting system is not designed to measure [wind turbine noise], and is not an appropriate way of measuring it." (The dB(A) weighting system is the basis of every wind turbine noise guideline in operation around the world.) There is also important brain research identifying parts of the brain, the Insula and the Amygdala, as being involved in Noise Sensitivity and how the body reacts to external stimuli, emotionally, physiologically, and so on. This helps us to understand why some individuals are badly affected while others are not. There is also a fascinating report that the contractility of human heart muscle, in an experimental setting, is reduced by around a quarter in the presence of Infrasound.

Global Warming will undoubtedly have detrimental health effects, so if Government is really serious about its reduction, erecting wind farms on upland blanket bog, as the larger wind farms typically are, should be sedulously avoided, please see the second attachment. This paper questions the wisdom of constructing wind farms on blanket bog because more carbon dioxide is released than is saved.

Several years ago, that champion of wind farms, The Irish Times, ran a series entitled 'Picture of Ireland' presented in the form of maps. One of these showed 'Where the Wind Farms are' (8-12-2012) which was followed a few months later by one showing 'Where are our Peatlands' (39-03-2013). One map could be superimposed on the other, such was the similarity between the distributions. In the latter map the peatlands were mainly of the blanket variety, predominantly on the western uplands. Exactly the same pattern is being repeated here. The text quoted research from Ireland's Environmental Protection Agency stating that:

"It is estimated that Ireland's remaining near-intact peatlands absorb the equivalent of 200,000 tonnes of carbon dioxide a year. Unfortunately, this process is reversed when peatlands are degraded. As a result, Irish peatlands are very significant net contributors to greenhouse gas emissions, releasing 9.6 million tonnes of carbon dioxide into the atmosphere each year. This is roughly equal to the total combined emissions of industry and commerce."

As you will appreciate, it is not just the enormous 'hardstandings' required for wind turbines but the many kilometres of service roads that need to be constructed which degrade the peatlands. I suppose another point worth mentioning is the thousands of miles of powerlines needed to distribute the unreliable electricity generated and these come with their own economic and health costs.

There is also a worrying stampede for Battery Energy Storage Systems which comprise banks of batteries, usually in in 40 feet long containers. They are not being installed to actually store energy for the long periods when the wind farm is not generating electricity, but, rather, to harmonise the frequency of the electrical output as it is notoriously ‘dirty’. They too carry their own health costs: Lithium-ion battery fires generate intense heat and considerable amounts of gas and smoke. The results have been validated using two independent measurement techniques and show that large amounts of hydrogen fluoride (HF) may be generated, ranging between 20 and 200 mg/Wh of nominal battery energy capacity. In addition, 15–22 mg/Wh of another potentially toxic gas, phosphoryl fluoride (POF_3), was measured in some of the fire tests. There are now reports from France of people and livestock being affected by the rare earth metals used in the magnets of the turbines’ generators.

The proliferation of single wind turbines which has taken place is also a source of concern. They are often second hand, with noisy gearboxes. They have often been detuned to harvest the greater subsidies that low output turbines attract, but sometimes are fitted with larger rotors so they are producing electricity more of the time. This is likely to ensure that the noise pollution will be greater, particularly as they are permitted with smaller setbacks from dwellings.

Autistic children are adversely affected by wind turbines and often become fixated on the movement of the turbines’ rotor blades, rendering their condition more severe and harder to manage. Similarly, children with photosensitive epilepsy are likely to be severely impacted by ‘shadow flicker’, caused by the turbine rotors with a light source behind them.

One question that you should be asking is why is so much effort and resources are being expended in developing wind-generated electricity when electricity generation only accounts for a small proportion of carbon emissions. Another question that is relevant is why carbon emissions have remained virtually unchanged despite all this input. The same findings are emerging from other European countries which have invested heavily in wind. A review of the Renewables programme is overdue here, and the French Government has committed itself to such an approach. Lastly, two senior Harvard Academics published a paper last December showing that wind turbines actually exert a climate-warming effect.

I trust that these observations are of some help.

Yours Sincerely

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Wind farms on undegraded peatlands are unlikely to reduce future carbon emissions

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HIGHLIGHTS

- Future wind farms located on undegraded peats will not reduce carbon emissions.
- This is due to projected changes in fossil fuels used to generate electricity.
- Future policy should avoid constructing wind farms on undegraded peats.

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ABSTRACT

Onshore wind energy is a key component of the renewable energies used by governments to reduce carbon emissions from electricity production, but will carbon emissions be reduced when wind farms are located on carbon-rich peatands? Wind farms are often located in uplands because most are of low agricultural value, are distant from residential areas, and are windy. Many UK uplands are peatlands, with layers of accumulated peat that represent a large stock of soil carbon. When peatlands are drained for construction there is a higher risk of net carbon loss than for mineral soils. Previous work suggests that wind farms sited on peatlands can reduce net carbon emissions if strictly managed for maximum retention of carbon. Here we show that, whereas in 2010, most sites had potential to provide net carbon savings, by 2040 most sites will not reduce carbon emissions even with careful management. This is due to projected changes in the proportion of fossil fuels used to generate electricity. The results suggest future policy should avoid constructing wind farms on undegraded peatlands unless drainage of peat is minimal and the volume excavated in foundations can be significantly reduced compared to energy output.

1. Introduction

Onshore wind energy is a key component of the renewable energies used by governments to reduce carbon (C) emissions from electricity production (Wang and Sun, 2012). Wind farms are often located in upland areas because most uplands are of low agricultural value, are distant from residential areas, and are windy (Cowell, 2010). Many UK uplands are peatlands, areas of land with an accumulated layer of peat, formed under waterlogged conditions from C rich plant material. These peatlands provide a special environment that hosts many rare fauna and flora (Bain et al., 2011) and represent a large stock of soil C, holding 48% of the total UK soil C stocks (Bradley et al., 2005). Because the high C content of a peat is partly due to waterlogged conditions, on drainage of the peatland, the peat can rapidly decompose, releasing large amounts of C as CO_2. This makes peat an important component of the UK C balance. Construction of wind farms can result in large losses of C due to removal of peat for foundations and due to drainage of peats around foundations, roads and other infrastructure, so it is important to ascertain whether C emissions will be reduced when wind farms are located on these C rich peatland soils.

With publication of the IUCN Peatlands Inquiry (Bain et al., 2011), peatlands have moved up the political agenda. For example, the Scottish Parliament's Rural Affairs, Climate Change and Environment Committee took evidence on the importance of peatlands for climate change mitigation in April 2012 (Scottish Parliament, 2012). Furthermore, following the decision at the 17th Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in Durban, December 2011, to include wetland drainage and re-wetting as an electable activity under Kyoto Article 3.4 (UNFCCC, 2011), net removals of C from the atmosphere by peatlands can now be included in the National Inventories of Annex I (industrialised) countries, to help meet Kyoto Protocol

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targets. The C balance of peatlands has, therefore, never been more important in policy terms, so any energy development on peatland requires scrutiny in terms of how it impacts upon the C and greenhouse gas balance.

When wind farm sites are drained for construction, there is a higher risk of net C loss if they are sited on peatlands than on mineral soils. A method to account for all C emissions attributable to a wind farm located on a peat soil has been developed by Nayak et al. (2010), widely adopted by the wind industry, and is currently being used by the Scottish Government in planning large-scale developments on peatlands (Scottish Environment Protection Agency (SEPA), 2012). Calculations using this approach suggested that wind farms on peats could reduce net C emissions if sites were strictly managed for maximum retention of C (Nayak et al., 2010). However, these calculations assumed that the present day fossil fuel mix would otherwise have been used to generate the electricity replaced. Here we examine the impacts on net C emissions of projected changes in the proportion of fossil fuels used to generate electricity.

2. Materials and methods

2.1. Calculation of carbon payback time

The purpose of using wind as a source of energy is to continue to provide the energy needed by society while reducing net C emissions from burning of fossil fuels (Aboumahboub et al., 2012). In order for a wind farm to provide a net reduction in C emissions, the losses of C due to the wind farm development must be less than the C savings achieved by avoiding fossil fuel use. This is often expressed as the C payback time, $t_{Cpayback}$ (years); the ratio of the total C losses, L_{tot} (t CO_2 eq.), to the annual C savings, $S_{turbine}$ (t CO_2 yr^{-1}) (Gibbs et al., 2008),

$$t_{Cpayback} = \frac{L_{tot}}{S_{turbine}} \quad (1)$$

If the C payback time is more than the lifetime of the wind farm, then no net reduction in C emissions is achieved.

2.2. Calculation of total carbon losses

In order to account for the C losses from the full life cycle of direct and indirect supply chain C inputs into the wind farm, a hybrid life cycle analysis (LCA) methodology can be used (Wiedmann et al., 2011; Acquaye et al., 2012). In this paper, we estimate the net loss of C due to wind farm development on peatland using the process LCA approach of Nayak et al. (2010) to calculate the net loss of C, L_{tot}, as the sum of

- loss of C due to production, transportation, erection, operation and dismantling of the wind farm;
- loss of C due to backup power generation;
- loss of C-fixing potential of peatland;
- change of C stored in peatland (due to peat removal and changes in drainage);
- C saving due to improvement of habitat; and
- loss of C-fixing potential and C stored in trees as a result of forestry clearance.

In this approach, loss of C due to production, transportation, erection, operation and dismantling of the wind farm is either supplied as an input value or estimated as a function of the turbine capacity. Losses of C emission savings due to backup power generation are calculated from the reserve capacity required for backup, the emission factor of the backup fuel and the reduced thermal efficiency of the reserve generation facilities due to the plant running at sub-optimal rate (Dale et al., 2004). The loss of C-fixing potential of the peatland is calculated from the area affected directly by infrastructure as well as the area indirectly affected by drainage (Stewart and Lance (1991)). The C fixing capacity of each unit area of affected peatland is either supplied as an input or estimated from observed rates of C accumulation (e.g. Turunen et al., 2001) and the time required until successful habitat restoration. The change in C stored in the peatland due to peat removal is given by the volume of peat removed and the C content of the peat. The loss of stored C due to drainage is calculated from the rates of CO_2 and methane emissions at different water table depths and air temperatures, and the time to restoration of the hydrology at the site. Additional losses of stored C as dissolved and particulate organic C are estimated as a proportion of the total CO_2 emissions from the peat (Worrall et al., 2004). The C saving due to improvement of habitat can then be accounted for as a change in the time to restoration of the hydrology and a change in the C accumulation rate. The loss of C-fixing potential and C stored in trees as a result of forestry clearance can also be included using estimates of the rate of C sequestration in the different tree species (Cannell, 1999). One process that has not been included in this approach is peat erosion due to catastrophic events, such as peatslides. Strong guidelines exist for minimising peatslide risk (e.g. Scottish Executive 2006), and it is assumed here that these guidelines are followed so that such events do not occur.

2.3. Calculation of annual carbon savings

The annual C saving achieved by avoiding fossil fuel use, $S_{turbine}$ (t CO_2 yr^{-1} $turbine^{-1}$), is given by the annual energy output from the turbine, $\varepsilon_{turbine}$ (MW h yr^{-1} $turbine^{-1}$), and the emissions that would have been incurred if that energy had been obtained from the mix of fuels replaced by the wind farm (the emission factor), EF (t CO_2 MW h^{-1}, Nayak et al., 2010),

$$S_{turbine} = \varepsilon_{turbine} \times EF \quad (2)$$

This means that the C payback time is inversely proportional to the average emission factor observed over the lifetime of the wind farm, EF_{ave} (t CO_2 MW h^{-1}),

$$t_{Cpayback} = \frac{L_{tot}}{\varepsilon_{turbine} \times EF_{ave}} \quad (3)$$

2.4. Input values for baseline calculations

Baseline calculations of the C payback time and net C emissions for wind farms on peatlands were done for a typical UK wind farm. This was defined as realising 30% of the turbine capacity (capacity factor), with an average annual air temperature of 9 °C, C content of dry peat 80%, water table depth of 0.2 m, regeneration time of bog plants 25 years, and C accumulation rate of bog plants 0.25 t C ha^{-1} yr^{-1}. Turbines were assumed to have a power of 2 MW and foundations of 18 m × 18 m × 0.9 m deep with associated hard-standing of 40 m × 22 m × 0.1 m depth, and a lifetime of 25 years. The effects of changes in site conditions and management were tested by adjusting input variables across the potential range of conditions; extent of drainage was adjusted between 0 m and 150 m, foundation dimensions between (10 m × 10 m) and (50 m × 50 m), length of non-floating access track from (0 km $turbine^{-1}$ to 1 km $turbine^{-1}$), and depth of peat drained between 1 m and 5 m.

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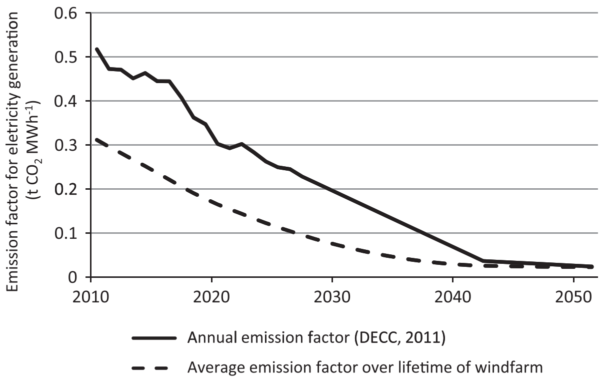

Fig. 1. Changes in emissions from the mix of fuels used to produce electricity in the UK. Average emission factor over the lifetime of a wind farm calculated assuming the lifetime of a wind farm is 25 years.

2.5. Emission factors

All calculations presented in this paper used the grid mix emission factors for the UK (Department of Energy and Climate Change (DECC), 2011) averaged over the assumed 25 year lifetime of the windfarm as shown in Fig. 1.

When calculating the potential of a wind farm to decarbonise electricity generation, the C emissions from the wind farm are usually compared to the emissions from the fossil fuels it replaces, so only the contribution of fossil fuels to the grid mix are accounted for in the emission factor chosen (e.g. Scottish Environment Protection Agency (SEPA), 2012). By contrast, in calculating whether a wind farm will provide an emission saving over other potential sources of electricity generation (fossil fuels, wind farms on mineral soils, tidal, nuclear etc), we need to compare the emissions from the wind farm to all the other types of electricity generation it will replace. Therefore, in these calculations, it is the total grid mix that is used, including both fossil fuel and renewable sources. This then directly compares the emissions that would occur if a wind farm was constructed on a peatland to the emissions that would occur if electricity was generated by any other means.

The average emission factor over the lifetime of the windfarm is used because emission factors from the mix of fuels used to generate electricity are projected to decrease in the future, due to use of Combined Cycle Gas Turbines up to 2025, and a higher proportion of renewable energies after 2025 (Department of Energy and Climate Change (DECC), 2011). This results in a change in the average emission factors as shown, for example, for the UK in Fig. 1, and a consequent change in the C payback time of wind farms constructed in the future. Similar decreases are expected in other countries, due to a move to a higher proportion of low-C power technologies; renewable and nuclear power are expected to account for more than half of all new power generation capacity added worldwide between 2010 and 2035 (International Energy Agency (IEA), 2011).

2.6. Effect of emission factor on net carbon saving at different sites

The threshold emission factor at which a site provides no net C saving, indicated by the C payback time exceeding the lifetime of the wind farm, is highly dependent on the conditions at the site, mainly the depth of the peat drained and the extent of drainage (Nayak et al., 2010). Therefore, these two variables were used to describe the range of sites that might be encountered. The depth of peat drained was assumed to range between 1 m and 5 m. There is considerable debate over typical extents of drainage observed in peats, with some authors suggesting that the drainage impact of ditches can extend as far as 400 m downslope (Lindsay, 2010), while an extensive global review of recommended drain spacings (McAfee, 1984) observed that drains are seldom spaced more than 40 m apart, suggesting the extent of drainage impact should also be considered within the same distance. This disagreement may be due to the formation of natural pipes within drained peats, which can significantly increase the extent of drainage over the lifetime of the wind farm (Holden, 2006), but would not be observed in a newly drained peatland and so would not be reflected in the positioning of drainage ditches. To capture the full breadth of scientific opinion, the extent of drainage was allowed to range from 0 m to 400 m.

The C payback time, $t_{Cpayback}$ (years), at a site was described with respect to the average emission factor during the lifetime of the wind farm by fitting an equation to the results obtained across the range of expected conditions,

$$t_{Cpayback} = a\ x\ EF_{ave}{}^{-b} \quad (4)$$

where a and b are constants that have been selected to provide the best fit between the equation and the results; for the UK, values published by Department of Energy and Climate Change (DECC) (2011) give a range of $EF_{ave}=0.025$ to 0.45 t CO_2 MW h^{-1} (Fig. 1).

By substituting $t_{Cpayback}=25$ years (typical lifetime of a wind farm) into Eq. (4) and rearranging, an equation was derived for the emission factor where the C payback time exceeds 25 years, EF_{25yrs} (t CO_2 MW h^{-1}), and so the wind farm provides no net C saving

$$EF_{25yrs} = \left(\frac{25}{a}\right)^{1/-b} \quad (5)$$

By running the model at sites with different extents of drainage (0–400 m) and depths of peat drained (1–5 m), the values of a and b were derived for the different sites, and Eq. (5) was used to calculate EF_{25yrs} for each. From these results, a more general equation to determine EF_{25yrs} from the extent of drainage, D (m), was derived,

$$EF_{25yrs} = eD^2 + fD + g \quad (6)$$

where e, f and g are constants that are dependent on the depth of drained peat, again fitted to provide the best fit between the equation and the results. Using the standard quadratic formula (Sterling, 2010) to factorise Eq. (6) gives the extent of drainage above which there will be no net C saving, D_0 (m), for any given average emission factor, EF_{ave} (t CO_2 MW h^{-1})

$$D_0 = \frac{-f \pm \sqrt{(f^2 - 4e(g - EF_{ave}))}}{2e} \quad (7)$$

Because the negative term results in a negative value for D_0, which has no physical meaning, this is resolved to

$$D_0 = \frac{-f + \sqrt{(f^2 - 4e\ (g - EF_{ave}))}}{2e} \quad (8)$$

Finally, Eq. (6) was translated into the year after which the wind farm will provide no net C saving, Y_0, by fitting a polynomial equation to the average emission factors.

Calculations were completed for sites that were managed for maximum C retention (hydrology restored on completion of construction, floating roads used and no additional infrastructure installed), and for similar sites where hydrology was not restored, floating roads were assumed to sink, or additional infrastructure (such as cable trenches, borrow pits and equipment enclosures) was constructed. The impact on net C savings of each of these assumptions was investigated in turn.

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3. Results

3.1. Changes in carbon payback time with emission factor

Changes in C payback time, for an example wind farm, due to projected changes in the average emission factor over the lifetime of the wind farm are shown in Fig. 2. The change in average emission factor is represented in Fig. 2 as the year of wind farm construction. As the extent of drainage increases, year of construction when the C payback time exceeds the assumed 25 year lifetime of the windfarm (and so no net C benefit of constructing the windfarm is realised) decreases. In this example, for an extent of drainage of 50 m, the C payback time exceeds the lifetime of the windfarm by year of construction 2040; for a 150 m extent of drainage, this will occur by 2030.

3.2. Effect of the emission factor on net carbon saving at sites managed for maximum carbon retention

Fig. 3 shows the equation derived for C payback time assuming an extent of drainage of 25 m and depth of peat drained as indicated in the baseline measurements (Section 2.4). Similar relationships were derived across the range of extents of drainage and peat depths simulated, and used to derive equations for the value of the emission factor when no net C saving is achieved, EF_{25yrs}.

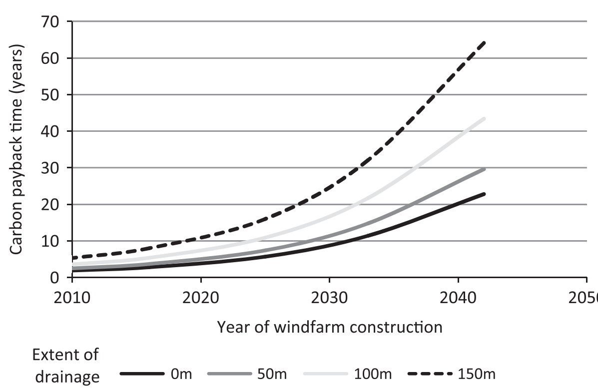

Fig. 2. Changes in carbon payback time for an example wind farm due to projected changes in average emission factor over the lifetime of the wind farm. Carbon payback time calculated by the method of Nayak et al. (2010) for an example wind farm with 2 MW turbines with foundations of 18 m × 18 m × 0.9 m deep, associated hard-standing of 40 m × 22 m × 0.1 m depth, managed for maximum carbon retention (using floating roads and no additional infrastructure) and a lifetime of 25 years.

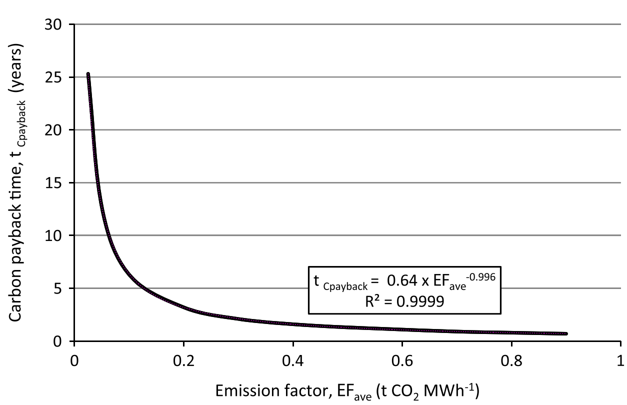

Fig. 3. Carbon payback time calculated for a range of emission factors for a typical UK site as given in the methods summary, assuming extent of drainage 25 m, no drainage of access tracks and restoration of the hydrology immediately following completion of foundations.

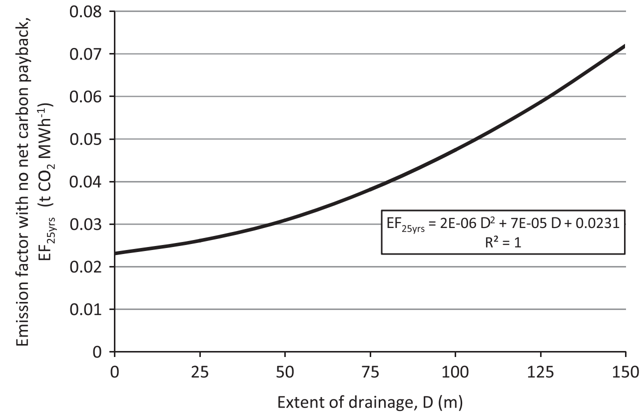

Fig. 4. Emission factor where no net C payback is achieved for a typical UK site as given in the methods summary across a range of extents of drainage, assuming depth of drained peat of 1 m, no drainage of access tracks and restoration of the hydrology immediately following completion of foundations.

Fig. 4 shows the equation derived for the emission factor where no net C saving will be achieved (EF_{25yrs}) with respect to the extent of drainage, D (m), for the example of peat drained to 1 m. The values of e, f and g obtained for different depths of drainage are shown in Table 1.

As illustrated in Fig. 5, the year associated with the average emission factor derived from the UK grid-mix emission factors provided by Department of Energy and Climate Change (DECC) (2011) is given by

$$Y_0 = 1994.79 \times EF_{25yrs}{}^{-0.0065} \quad R^2 = 0.979 \tag{9}$$

This equation was then used to translate the emission factors with no net C savings into the year of construction of the wind farm (Fig. 6). The results show that in 2010, if sites are managed for maximum C retention by using effective floating roads, minimising infrastructure such as equipment compounds and cable trenches, and restoring the hydrology of peat around the foundations immediately after construction, most sites have the potential to provide net C savings even if a higher extent of drainage is assumed (Fig. 6). However, by the end of the lifetime of sites approved in 2010 (~2040), even sites with less than 25 m extent of drainage will provide no net C savings. This is due to the projected change in the emission factors.

3.3. Effect of emission factor on net carbon saving if hydrology is not restored

Similar calculations to those described in Section 3.2, but assuming sites were not restored, provide alternative values for the constants defining the emission factors where no net C savings are achieved at different extents of drainage and depths of peat drained (e, f and g, Eq. (6));

$$e = (-3 \times 10^{-7})d^2 + (1 \times 10^{-5})d - (4 \times 10^{-6}) \tag{10}$$

$$f = (-7 \times 10^{-6})d^2 + (5 \times 10^{-4})d - (8 \times 10^{-5}) \tag{11}$$

and

$$g = (1.8 \times 10^{-3})d - (2.13 \times 10^{-2}) \tag{12}$$

where d is the depth of drained peat (m).

The results of these calculations are given in Fig. 7. They show that even in 2010, significant C losses are expected at a high proportion of sites (Fig. 7). This suggests that the hydrology of the peat around foundations should never be left unrestored on

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Table 1
Parameters describing the emission factor where C payback time exceeds 25 years for different depths of drained peat.

Depth of drained peat, d (m)	e[a]	f[a]	g[a]	R^2
1	2×10^{-6}	7×10^{-5}	0.0231	1.0
2	2×10^{-6}	1×10^{-4}	0.0247	1.0
3	3×10^{-6}	1×10^{-4}	0.0268	1.0
4	3×10^{-6}	1×10^{-4}	0.0284	1.0
5	3×10^{-6}	1×10^{-4}	0.0301	1.0

[a] e, f and g are constants that are dependent on the depth of drained peat, fitted to provide the best fit between the equation and the results.

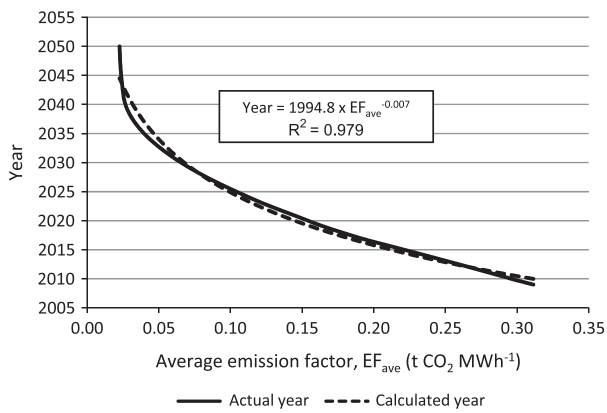

Fig. 5. Year corresponding to the average emission factor observed over the 25 year lifetime of a wind farm in the UK, EF_{ave}. The actual values (as shown in Fig. 1) are represented by the solid line. The values calculated by the equation fitted to the actual values are represented by the dotted line. The graph illustrates the goodness of fit between the two sets of values.

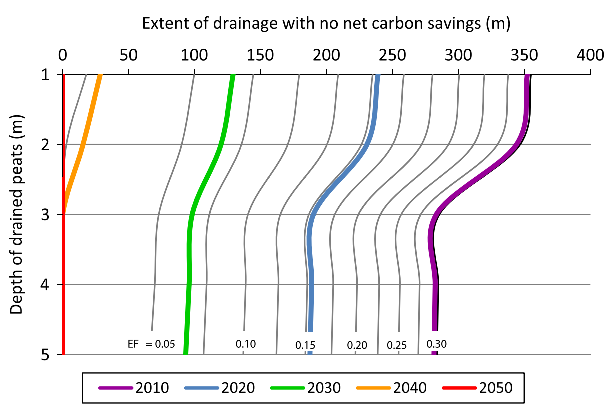

Fig. 6. Extent of drainage where no net carbon savings occur, at sites with different depths of drained peat and hydrology, that are fully restored on completion of construction. Carbon savings calculated by the method of Nayak et al. (2010) for example wind farm with lifetime of 25 years and 2 MW turbines with foundations of 18 m × 18 m, associated hard-standing of 40 m × 22 m × 0.1 m depth and managed for maximum carbon retention (floating roads and no additional infrastructure). Contours show results assuming different lifetime average emission factors. Coloured contours indicate results according to year of wind farm construction.

completion of construction of the wind farm as this will result in net C emissions from most sites.

3.4. Effect of additional infrastructure on net carbon saving

If floating roads sink or significant amounts of infrastructure, such as cable trenches, borrow pits and equipment enclosures are constructed, net C losses from wind farms constructed on peatlands could be very large. Additional infrastructure adds to the impact that the emission factor has on the C payback time.

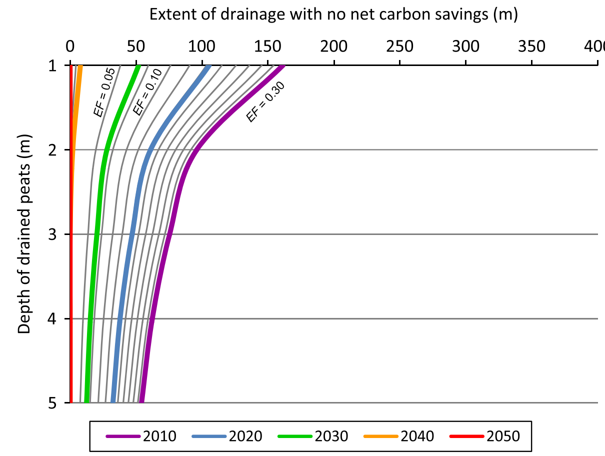

Fig. 7. Extent of drainage where no net carbon savings occur at sites with different depths of drained peat if hydrology is not restored on completion of construction. Carbon savings calculated by the method of Nayak et al. (2010) for an example wind farm with a lifetime of 25 years and 2 MW turbines with foundations of 18 m × 18 m, associated hard-standing of 40 m × 22 m × 0.1 m depth and managed for maximum carbon retention (using floating roads and no additional infrastructure).

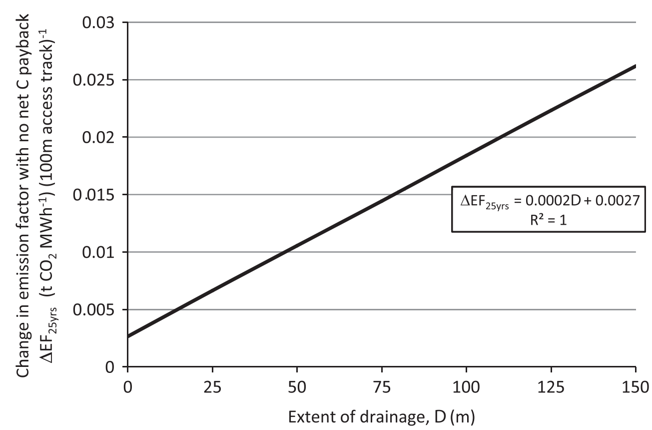

Fig. 8. Change in emission factor with no net C payback due to drainage of access tracks for a typical UK site as given in the methods summary across a range of extents of drainage, assuming depth of drained peat of 1 m and restoration of the hydrology immediately following completion of foundations.

For example, if access tracks are constructed as either rock-filled or excavated roads, or if floating roads sink following construction and sustained use, the access track adds to the C payback time, and so the impact of the wind farm on C emissions increases, resulting in no net saving in C occurring at a higher emission factor (an earlier year of construction) than was observed without the access track. By repeating the above calculations but including the additional infrastructure on the site, an equation was derived for the change in the emission factor where the wind farm provides no net C saving due to the extra infrastructure, ΔEF_{25yrs} ((t CO_2 MW h^{-1}) (unit of infrastructure)$^{-1}$). As shown in Fig. 8, for drained access tracks, the equation for ΔEF_{25yrs} ((t CO_2 MW h^{-1}) (100 m access track)$^{-1}$) is linear

$$\Delta EF_{25yrs} = (h \times D) + i \quad (R^2 = 0.9995) \tag{13}$$

and has slope, h, of 0.0002 (t CO_2 MW h^{-1}) (100 m access track)$^{-1}$ (m extent of drainage)$^{-1}$, and an intercept, i. The value of i varies with the depth of the access track, d (m), and is given by $i = 0.0027d - 0.0001$ (t CO_2 MW h^{-1}) (100 m access track)$^{-1}$. For the example of drained roads, Eq. (13) gives the change in the emission factor where no net C saving is achieved with every 100 m of road drained. Using Eq. (9), this translates to sites showing no potential for net C saving ~2 years earlier for every 100 m of track drained.

3.5. Effect of turbine power on net carbon saving

The C payback time for a wind farm is calculated from the ratio of the net loss of C due to the wind farm development with the yearly C savings achieved by avoiding fossil fuel use (Eq. (1)). The yearly C savings can be calculated from the typical percentage of the turbine capacity realised at the site (the capacity factor), p_{cap} (%), the power of the turbine, P (MW), the number of turbines, n_{turbine}, and the average emission factor, EF_{ave} ($\text{t CO}_2\ \text{MW h}^{-1}$) (Nayak et al., 2010),

$$S_{fuel} = 24 \times 365 \times \frac{p_{cap}}{100} \times n_{turbine} \times P \times EF_{ave} \quad (14)$$

A site that provides no net C saving will have a C payback time equivalent to the wind farm life ($t_{Cpayback} = 25$ years). Substituting this into Eq. (1, 14) and rearranging gives an expression for the emission factor where no net C saving is achieved, $EF_{25\text{yrs}}$ ($\text{t CO}_2\ \text{kW h}^{-1}$)

$$EF_{25\text{yrs}} = \frac{L_{tot}}{25 \times 24 \times 365 \times (p_{cap}/100) \times n_{turbine} \times P} \quad (15)$$

Turbines are likely to be of higher power in the future and have associated larger foundations (Hansen et al., 2004). As shown in Eq. (15), the emission factor where no net C saving is achieved, $EF_{25\text{yrs}}$ ($\text{t CO}_2\ \text{kW h}^{-1}$), is inversely proportional to the turbine power, P (MW). So if a turbine with power P_1 achieves no net C saving at emission factor $EF_{25\text{yrs}}$, then if the size of the foundations remain unchanged, a turbine of power P_2 will achieve no net C saving at emission factor $EF_{25\text{yrs}} \times (P_1/P_2)$. Therefore, to maintain the current level of C savings, the power of the turbine relative to the size of the base must increase in proportion to the decrease in the average emission factor over time. For example, for a turbine to provide a net C saving at sites with extent of drainage up to 100 m and peat drained to a depth of 5 m in 2040, the ratio of $EF_{25\text{yrs}}/P$ in 2040 would need to be equivalent to the ratio in 2030 (Fig. 6). This means that the turbine power would need to increase by a factor of 2.45 for the same size of foundations.

4. Discussion

The above calculations illustrate that changes in emission factors expected by 2050 are likely to reduce the C savings achieved when wind farms are located on undegraded peatlands. Even without accounting for the impact of additional infrastructure, if sites are restored, drainage for turbine foundations will result in no net C savings at most sites by ~2040, and if they are not restored, net C losses are already likely in 2010 at many of the sites constructed. Construction of infrastructure adds to the C losses; drainage of roads results in no net C savings ~2 years earlier for every 100 m of track drained. These effects may be partially offset by increases in turbine power with respect to the size of foundations. This may be facilitated by development of technologies such as piling (Tomlinson and Woodward, 2008), which reduce the need to excavate peats, even with larger turbines. If wind farms are not decommissioned at the end of their lifetime, but are instead used to site new turbines, there may be further potential for net C savings at the recommissioned sites by reducing the need to excavate new foundations through positioning the new turbine on top of the foundations of the previous turbine. In the future, because of changes in the emission factors, if wind farms located on peatlands are to provide a net C saving, it is essential that such construction options are used to maximise the ratio of the turbine power to the volume of foundations.

There is also potential to reduce the C payback time by using the financial resources available to wind farm companies to restore previously degraded peatlands and offset the losses from the wind farm itself. These practices might include restoration of previously degraded areas of the site, such as borrow pits, mined areas, existing roadways or heavily eroded gullies. Assuming that the hydrological status of the peat can be restored to a steady state that will allow the habitat to regenerate, the volume of peat restored should at least be greater than the volume of peat excavated for the construction, with additional restoration needed to account for any peat drained. The volume that should be restored will increase with delays in completion of restoration; if the restoration was complete only half-way through the wind farm life, then the volume of peat that should be restored would be doubled.

Further suggestions have been made that forestry planting could be used to offset the C lost from the wind farm. However, forestry planting can only be used to offset C losses due to felling of trees; losses due to decomposition of peats cannot be compensated for by planting trees as the longevity of the pool of C held in the trees is much less than that of the C held in the peats.

5. Conclusions and policy implications

Wind farms constructed on undegraded peatlands introduce higher risks of net loss of C than wind farms constructed on mineral soils, and must be strictly managed for maximum C retention if a net C saving is to be realised. Previous work (Nayak et al., 2010) has indicated that a benefit to terrestrial C stocks can be achieved by responsible management of sites and targeted use of resources to improve previously degraded sites. However, when projected changes in emission factors are accounted for, the potential for C saving is very much reduced and most peatland sites will show no net C saving. Even if constructing wind farms on undegraded peatlands is of value in reducing C emissions today, it is not likely to be so in the future. This suggests that the construction of wind farms on undegraded peatlands should be avoided. If this results in a reduction in renewable energies, the predicted reduction in emission factors might not be realised. However, given that wind farms could be sited solely on non-peatland sites, and that other forms of renewable energy are available to meet emission reduction targets, the exclusion of wind farm development on peatland would not be expected to significantly impact future emission factors. Given the clear advantages in terms of C payback time of locating wind farms on mineral soils, and the marginal future C savings provided by locating wind farms on peats, construction of wind farms on undegraded peatlands is best avoided wherever practicable.

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Environmental Noise Pollution: Has Public Health Become too Utilitarian?

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Abstract

Environmental noise pollution is an ever-increasing problem. The various sources: Aircraft, Road Traffic and Wind Farms are reviewed, but the latter source, because of the intrusive, impulsive and incessant nature of the sound emitted, is the major focus of this review. Wind turbines produce a range of sound but it is the Infrasound and low frequency noise which deserves special attention. Infrasound is considered to be below the range of human hearing so it is not measured in routine noise assessments in the wind farm planning process. There is, however, evidence that many can register it and a sizeable minority is sensitive, or becomes sensitised to it. The actual route of transmission still requires elucidation. The net effect of the entire range of noise produced is interference with sleep and sleep deprivation. Sleep, far from being a luxury is vitally important to health and insufficient sleep, in the long term, is associated with a spectrum of diseases, particularly Cardiovascular. The physiological benefits of sleep are reviewed, as is the range of diseases which the sleep-deprived are predisposed to. Governments, anxious to meet Green targets and often receiving most of their advice on health matters from the wind industry, must commission independent studies so that the Health and Human Rights of their rural citizens is not infringed. Public Health, in particular, must remember its roots in Utilitarianism which condoned the acceptance of some *Collateral Damage* provided that the greatest happiness of the greatest number was ensured. The degree of *Collateral Damage* caused by wind farms should be totally unacceptable to Public Health which must, like good government, fully exercise the *Precautionary Principle.* The types of study which should be considered are discussed. Indeed, the father of Utilitarian Philosophy, Jeremy Bentham, urged that government policy should be fully evaluated.

Keywords

Environmental Noise Pollution, Wind Farms, Infrasound, Health Impacts, Public Health, Utilitarianism, Collateral Damage, Precautionary Principle

1. Introduction

There are a number of emerging threats to Public Health, and some of these can be directly ascribed to human activity, chief among which are Global Warming, air pollution and environmental noise pollution. This paper will concentrate on the issue of environmental noise pollution and examine how modern Public Health has lived up to its responsibilities in controlling it. Over a century ago, the Nobel Prize-winning microbiologist, Robert Koch, predicted [1] "One day man will have to fight noise as fiercely as cholera and pest (plague)." The accuracy of this prediction is attested to by the statement [2] from the United States Environmental Protection Agency that, "The over-all loudness of environmental noise has been doubling every ten years in pace with social and industrial growth, and, if allowed to continue unchecked, the cost of alleviating it in the future may be insurmountable." Perhaps surprisingly, this statement is more than 40 years old, yet the problem has been growing, unchecked, ever since.

From an evolutionary perspective, an awareness of sound is essential to alert us of incipient danger, but our aural acuity may have left us vulnerable to when it is present in excess. The earliest problems arose with the introduction of noisy industrial processes a couple of centuries ago, which induced deafness [3]. We are now being bombarded with noise pollution from diverse sources, which predisposes us to a range of diseases. Light radiation ranges from Ultraviolet to Infrared, and apart from its intensity, its wavelength will determine its effect on the receiver: typically different wavelengths in the Ultraviolet range have different effects on our skin [4]. Similarly, it is not just the amplitude of noise which brings health consequences, but also, its "frequency content" (considering the sound as a stimulus rather than how frequency in the audible range is perceived as pitch).

Sound is caused by a series of pressure pulsations, or more broadly, by changes in air pressure. The spectrum of sound [4] frequency ranges from >1 to more than 20,000 cycles per second or Hz, with the range up to 20 Hz classified [5] as Infrasound, >20 - 200 Hz as low frequency sound (the lowest note on a piano has a frequency of 33 Hz and Middle C, 262 Hz [6]), >200 - 20,000 Hz as the human auditory range, and >20,000 Hz as Ultrasound. Strictly, pressure pulsations outside our auditory range cannot be described as sound but they are still able to exert an effect on us [5].

As with light, sound's effects on human health are not only determined by its intensity, or amplitude, but also by its frequency and the rate of change in amplitude. The term Infrasound is confusing, because how could sound which we are unable to hear have an effect on us? Perhaps a better way to look at it would be in terms of pressure pulsations. There is increasing evidence that Infrasound is perceived by the brain [7], and possibly by other sensory systems' vibratory receptors [8]: in the vestibular organ of balance, skin and joints, rather than by those transmitting auditory sensation [7]. Another problem with noise in the lower registers is that it persists longer, travels further and, thanks to diffraction, can turn corners [6].

This, from another evolutionary perspective, is no surprise. Many of our fellow mammals use Infrasound extensively for communication: e.g., giraffes, rhinoceroses, whales and elephants—the latter are capable of sensing distant thunderstorms, because of the Infrasound the storms emit, from over a hundred kilometres away [9], and set off in that direction in the knowledge that they will find water and green vegetation to consume. Humans carry a large range of genes which were acquired in our evolutionary past, but which are now redundant. Sometimes however, these are expressed, for example when, occasionally, someone grows a tail [10]. Olfactory receptor (OR) genes provide a good example of genes which humans possess but do not express. Mammals have over 1000 OR genes and these constitute the largest mammalian gene superfamily. In humans about 60% of these are pseudogenes and have been annulled through mutation [11]. In other primates, the pseudogene rate is about half of this. It is postulated that reduced chemosensory dependence in man drives this OR gene disruption. Individual differences in gene-expression might also explain why a small, but significant, proportion of the population may be more sensitive to the effects of Infrasound than others, and to noise in general [7]. An alternative hypothesis is that sufferers have been "sensitized" through past exposure [5], although both factors could contribute.

This review will concentrate on the adverse health effects associated with environmental noise, particularly those due to the Infrasound and low frequency noise emitted by industrial wind turbines. Some of the adverse health effects are due to sleep deprivation, and the evidence linking it to several diseases, particularly cardiovascular, will be discussed. The control of wind farm noise emissions, and its effectiveness, will be reviewed along with the appropriateness of the Guidelines governing noise limits, and where wind farms are sited. The studies which need to be mounted will then be described. The history of Public Health will be discussed, including the seminal role that Utilitarian Philosophy (the greatest happiness of the greatest number) played in its inception. The response of Public Health to new health threats will be evaluated in the light of the concepts of *Collateral Damage* and the *Precautionary Principle*. The overall aim is to evaluate the adverse health effects of industrial wind turbines and the adequacy of the Public Health response to the problems arising. In particular, the adequacy of the protection of the Health and Human Rights of rural citizens whose health is compromised by wind turbines will be scrutinized.

2. Literature Review

2.1. Extent of the Problem

The problem of noise pollution has been justly highlighted in two recent World Health Organisation reports. The first of these, entitled 'Night Noise Guidelines for Europe', stated [12] that "… environmental noise is emerging as one of the major Public Health concerns of the twenty-first century." It observed that, "Many people have to adapt their lives to cope with the noise at night," and that the young and the old are particularly vulnerable. This is because hearing in young people is more acute and, in older people, a loss of hearing of higher sound frequencies renders them more susceptible to the effects of low frequency noise [13]. A more recent World Health Organisation report calculated [14] that more than a million healthy life years (Disability Adjusted Life Years) are lost due to environmental noise annually in western EU member states. The vast bulk of these are lost because of noise-induced sleep disturbance, followed by 'Annoyance.' This is a construct assembled from subjects' responses to a questionnaire, where subjects are asked to indicate their 'Level of Annoyance' on a scale [15]. Annoyance is a common finding reported in a population exposed to environmental noise. It is difficult to define accurately, but one authority maintains that it can result from noise interfering with daily activities, feelings, thoughts, sleep or rest, and might be accompanied by negative responses, such as anger, displeasure, exhaustion and stress-related symptoms [16]. It clearly is not a trivial state.

Sleep disturbance is serious if it leads to sleep deprivation [17], which is associated with a gamut of Cardiovascular Diseases (CVD), obesity, diabetes, and poor memory consolidation [1]. In an up-to-date meta-analysis of 160,867 subjects, in whom 11,702 cases occurred, insomnia symptoms were shown to be significantly associated with the risk of cardio-cerebral vascular events [18]; and even some cancers [19]. On top of this, inadequate sleep in children is associated with impaired memory and learning, poor cognitive function, mental health disorders, and obesity [20]. The mechanism for this is not well understood but it may be connected to higher levels of a cannabis-like chemical found in individuals who are deprived of sleep [21]. The latter is of concern because it tends to sow the seeds for diabetes and CVD in later life.

2.2. Importance of Sleep

There is an ever-mounting volume of research to show that sleep is essential for the brain and the physiological well-being of the entire body. Sleep deprivation interferes with learning, causing memory impairment because memory is laid down and reinforced during both the Slow Wave and Rapid Eye Movement phases of sleep. In mice, it has been shown that sleep plays a key role in promoting learning-dependent synapse formation and maintenance on selected dendritic branches, which contribute to memory storage [22]. There are a number of other adverse effects associated with sleep deprivation. Tired individuals are more likely to have road traffic accidents and injure themselves while operating machinery. During sleep, neurotoxins are removed from the brain [23]. Lately, an association between sleep deprivation and loss of brain volume has been demonstrated [24]. This study was based on serial MRI scans carried out in 147 community-dwelling adults. In addition, it has been demonstrated [25] that various inflammatory biomarkers are affected by sleep deprivation.

Sleep deprivation produced experimentally also very rapidly alters the expression in a wide range of genes, involving several body systems [26] [27]. This could explain the links between sleep deprivation and CVD where the putative intermediate risk factors include blood pressure, clotting factors, blood viscosity, and blood lipids and glucose [1]. The cardiovascular effects of environmental noise exposure have been reviewed recently in studies carried out in 11 countries. These compared aircraft, road and railway sources of noise: aircraft noise was identified as the most highly annoying, and railways the least [1]. It is unclear as to which frequencies are contributing most because very often the full acoustic spectrum is not assessed. Jet aircraft, in particular, produce Infrasound and low frequency noise in abundance, so people dwelling near airports suffer adverse health effects [28] [29].

Why has environmental noise pollution become such a problem? Air and road traffic have increased and industrial installations have tended to get bigger. There are noise limits set, but they may not always be enforced. The other aspect, which should be of great concern to Public Health, is that the cut-points established as safe for any factor whose risk is continuously distributed, are nearly always set too high—e.g., blood pressure and LDL cholesterol—and subsequently have to be revised downwards. Asbestos is a prime example, with the permitted level of asbestos being successively reduced over many years [30] until its use was banned in most developed countries. Airports invariably have night time restrictions on flying and road traffic noise tends to be less at night. Wind farms emit noise, sometimes for days on end, and this is a problem because they are being constructed in rural areas where background noise is low. It is a particular problem at night, because Infrasound persists long after the higher frequencies have been dissipated [6]. This paper will concentrate on the health effects of wind turbine noise, which has been shown [31] to be particularly troublesome because of its impulsive, intrusive and incessant nature.

2.3. Health Effects of Wind Turbine Noise

The major adverse health effects caused by wind turbines seem to be due to sleep disturbance and deprivation, with the main culprits identified as loud noise in the auditory range and low frequency noise, particularly Infrasound. This is inaudible in the conventional sense, and is propagated over large distances and penetrates the fabric of dwellings, where it may become amplified by resonance. A report [32] commissioned by the Scottish Government, which is investing in wind energy to a heroic degree, grudgingly accepts that wind turbine noise interferes with sleep. A recent Swedish study, conducted [33] on healthy volunteers in a sleep laboratory, has shown that the noise produced by wind turbines, particularly low frequency band amplitude modulation, is disruptive to sleep. This was indicated by an increase in electro-physiological awakenings, lighter sleep with more wakefulness, and reduced deep sleep and Rapid Eye Movement sleep.

A recent review identified [34] 146 potential papers assessing the effects of wind turbine noise, and after applying stringent criteria, came up with a shortlist of 18, of which eight were included in a meta-analysis. All studies were cross-sectional and a meta-analysis of six of these ($n = 2364$) revealed that the odds of being annoyed are significantly increased by wind turbine noise (OR: 4.08; 95% CI: 2.37 to 7.04; $p < 0.00001$). The odds of sleep disturbance were also significantly increased with greater exposure to wind turbine noise (OR: 2.94; 95% CI: 1.98 to 4.37; $p < 0.00001$). Four studies reported that wind turbine noise significantly interfered with Quality of Life. Furthermore, the visual perception of wind turbine generators was associated with a greater frequency of reported negative health effects. Visual perception and sound emissions (effects of emissions after propagation on the environment) are directly related to distance so studies need to carefully differentiate the two sources of annoyance to ensure that each is properly assessed.

Sleep deprivation has also been shown [35] to be associated with heart failure in the HUNT Study. The data are quite robust as they are based on 54,279 Norwegians free of disease at baseline (men and women aged 20 - 89 years). A total of 1,412 cases of heart failure developed over a mean follow-up of 11.3 years. A dose-dependent relationship was observed between the risk of disease and the number of reported insomnia symptoms: i) difficulty in initiating sleep; ii) difficulty in maintaining sleep; and iii) lack of restorative sleep. The Hazard Ratios were "0" for none of these; "0.96" for one; "1.35" for two; and, "4.53" for three; this achieved significance at the 2% level. This means that such a result could occur once by chance if the study were to be repeated 50 times. Significance is conventionally accepted at the 5% level.

Another important, recent study is MORGEN, which followed [36] nearly 18,000 Dutch men and women, free of CVD at baseline, over 10 - 14 years. In this period there were 607 events: fatal CVD, non-fatal Myocardial Infarction and Stroke. Adequate sleep, defined as at least seven hours a night, was a protective factor which augmented the benefits conferred by the absence of four traditional cardiovascular risk factors. For example, the benefit of adequate sleep equalled the protective contribution of not smoking cigarettes. Given that cigarette smoking is such a potent risk factor for CVD, this result is striking. The findings built on earlier ones from the MORGEN study [37]. It seems that adequate sleep is important in protecting against a range of CVDs which result when arteries of different sizes are compromised: large (coronary, cerebral) arteries in heart attacks and stroke, small arteries (arterioles) in heart failure. The mechanisms are obscure, but it is known, for example, that exposing mice to stress activates [38] hematopoietic stem cells, *i.e.* affects the immune system and accelerates atherosclerosis.

All of these studies share the weakness that they are "observational" as opposed to "experimental" and, as such, their results do not constitute "proof". The results from the experimental study of sleep deprivation of fairly short durations [26], which affected the expression of a large range of genes, sheds light on the

"Wind Turbine Syndrome (WTS)", a cluster of symptoms which includes sleep disturbance, fatigue, headaches, dizziness, nausea, changes in mood and inability to concentrate [39]. In this condition, Infrasound is a likely causal agent. Another report from HUNT has examined insomnia in almost 25,000 persons and has demonstrated [40] it to be a robust risk factor for incident physical and mental disease, which included several features of WTS.

This group has now shown, in another small intervention study, that mistimed sleep desynchronized from the central circadian clock has a much larger effect on the circadian regulation of the human transcriptome (*i.e.*, a reduction in the number of circadian transcripts from 6.4% to 1% and changes in the overall time course of expression of 34% of transcripts). This may elucidate the reasons for the large excess of cardiovascular events associated with shift work [27]. The results demonstrate that any interference in normal sleeping patterns is inimical to cardiovascular health.

The old admonition that "What you can't hear won't harm you" sadly isn't true. It is now known [41] that the organ of Corti in the cochlea (inner ear) contains two types of sensory cells: one row of inner hair cells which are responsible for hearing; and three rows of outer hair cells which are more responsive to low frequency sound. Another function of the outer hair cells is that, due to their extensibility, they can modify the sensitivity of the cochlea. This has relevance to low frequency hearing and also to detecting higher frequencies which are amplitude-modulated at lower, if not infrasonic, frequencies. The Infrasound produced by wind turbines is transduced by the outer hair cells and transmitted to the brain by Type II afferent fibres. The purpose is unclear as it results in sleep disturbance. This may well be the group which is also liable to travel sickness, which is a sizeable proportion of the population. Schomer and his colleagues have since advanced [42] the theory that as wind turbines increase in size they increasingly emit Infrasound with a frequency below 1 Hz (CPS). Below this frequency the otoliths in the inner ear respond in an exaggerated way in a susceptible minority who will suffer symptoms of WTS. Previously it was thought that the brain was only under the control of electrical and biochemical stimuli, but there is new evidence [43] that it is sensitive, in addition, to mechanical stimuli.

There were important studies carried out in the 1980s which appear to have been forgotten and which give a clue to the mechanisms involved. Danielsson and Landström carried out [44] a study in 20 healthy male volunteers who were bombarded with Infrasound for varying periods. Just 30 minutes' bombardment with 125 dB at 16 Hz resulted in a mean 8 mm increase in diastolic blood pressure. On the other hand, systolic BP was not affected, whereas the Pulse Pressure decreased. This could have important effects in those exposed to environmental Infrasound, for although the intensity may not be profound, chronic exposure might raise blood pressure a little. From a population perspective, this could raise the burden of CVD. Scientists at the University of Toronto Institute for Aerospace and the University of Waterloo found [45] variability in response in volunteers exposed to Infrasound under laboratory conditions using Infrasound of 8 Hz. The adverse responses of some individuals closely resembled motion sickness. They postulated that individual differences in the reaction to Infrasound might be explained by variability of inner-ear structure or central adaptive mechanisms.

As far back as 1996, the International Standards Organisation acknowledged [46] that motion sickness arises from low frequency oscillatory motion below 1 Hz. The report cites: "…a range of microscopic organs (mechano-receptors) distributed in the living tissues throughout the body that variously signal changing pressure, tension, position, vibratory motion, etc." This is highly intriguing as it seems extremely plausible that the same effect obtains for Infrasound in the same frequency range and this requires urgent clarification. Indeed, the incidence of motion sickness can be predicted from the magnitude, frequency, and duration of vertical oscillation [47]. There is also mounting evidence that jet engine Infrasound can induce Vibro-acoustic Disease [48]. It is recognized [49] that around 15% - 20% of individuals are seriously affected by the Infrasound and low frequency noise produced by aircraft, particularly jets.

A recent economic assessment of US environmental noise as a cardiovascular health hazard suggested that a reduction of 5 dB would reduce hypertension by 1.4% and coronary heart disease by 1.8%, with an annual economic benefit of USD3.9 billion. The threshold for the noise-exposed group was >55 dBA LDN, though there is evidence in the literature that there may be important impacts at even lower levels of noise exposure [50]. Invariably in assessing noise exposure the average sound levels are assessed, whereas it may be that it is the peaks of sound which do the damage. In a study of seals kept in captivity, it was shown [51] that repeated elicitation of the acoustic startle reflex led to sensitization, subsequent avoidance behavior and induced fear conditioning. The data indicated that repeated startling by anthropogenic noise sources might have severe effects on long-term behavior.

An Iranian paper has lately reported [52] sleep disturbance in wind turbine workers, 53 of whom fell into three groups: mechanics, security staff and officials. The results showed that there was a positive and significant relationship between age, workers' experience, equivalent sound level, and the severity of sleep disorder. When age was constant, sleep disorders increased by 26% for each 1 dB increase in equivalent sound level. In situations where the equivalent sound level was constant, an increase in sleep disorder of 17% occurred for each year of work experience. There was a difference in sound exposure between the different occupational groups: the effect of noise in mechanics was 3.4 times greater than in the security group and about 6.5 times greater than in the official group. Sleep disorder caused by wind turbine noise was almost twice as high in the security group in comparison to the official group. It was concluded that the noise generated by wind turbines has health implications for everyone exposed to it.

In a study reported [53] from Japan, 15 subjects were experimentally exposed to various sound stimuli, including recorded aerodynamic noise and Infrasound, along with synthetic periodic sound, and were evaluated by electroencephalography. The induced rate of *alpha*1 rhythm decreased when the test subjects listened to all the sound stimuli and decreased further with reducing frequency. In particular, the induced rate of *alpha*1 rhythm, when the sound stimulus lay in the frequency band of 20 Hz, produced the lowest rate of all. It was concluded that the subjects cannot relax comfortably when exposed to Infrasound.

The European Metrology Research Programme (EMRP) has now established that everyone, at least all 16 of the healthy 18 - 25-year-old volunteers studied, can perceive Infrasound down to 8 Hz [54]. This was the lowest frequency investigated and it is likely that even lower frequencies can be perceived. 'Perception' was assessed using functional magnetic resonance imaging (fMRI) and a significant response was detected which was localized within the auditory cortex and which was present down to 8 Hz. The signal strength of the blood-oxygen-level dependent (BOLD) signal showed a minimum at 20 Hz, so a further investigation of BOLD-signal's dependence on the loudness was carried out. A decreasing dynamic range of hearing in this frequency range was noted, accompanied by the finding that even sound signals with sound pressure levels only slightly above the threshold will be registered as annoying.

Several details in the brain imaging results suggested that, at frequencies around about 20 Hz, the perception mechanism might change or is realized by a combination of different processes. One hypothesis is that a somatosensory excitation of the auditory cortex contributes at these frequencies [54]. Thus, the idea is floated that we are perceiving Infrasound directly through our body surface. This fits in with the concept of the vibration of body structures espoused by Persinger [6]. In the Cape Bridgewater study, in which turbines were intermittently turned on and off, the subject who could best predict whether or not the rotors were in motion or not was profoundly deaf [55].

The latest EMRP study conducted on 14 subjects has demonstrated [56], using fMRI, that Infrasound of 12 Hz administered at sound pressure levels just below the hearing threshold can induce changes in neural activity across several brain regions. Some of these regions are known to be involved in auditory processing, while others are recognized as playing key roles in emotional and autonomic control. Paradoxically, these effects were not observed when subjects were exposed to Infrasound of 12 Hz above the hearing threshold, because, apparently, the brain can adjust to it. These findings provide intriguing evidence that continuous exposure to subliminal Infrasound may be harmful to the human brain. Such physiological or even psychological effects could be mediated via a subconscious processing route. The transient up-regulation of these brain regions in response to Infrasound at this level may therefore reflect an initial stressor response, with symptoms becoming established through constant exposure.

The EMRP authors observe [56] that a large part of the Infrasound that we are exposed to in our daily environment is produced by continuous sources such as wind-turbines and traffic. They argue that it is these sources of constant and subtle Infrasound, which may not attain a level exceeding the threshold of perception, which exert influences on the nervous system. Thus it seems that low levels of Infrasound really are capable of getting in 'under the radar'. It is this very level of Infrasound which authorities such as Leventhall state cannot harm you and which WHO dismisses as having no physiological or psychological effects [56].

In addition, wind turbines can, and do, cause accidents by collapsing, blade snap, ice throw, and even going on fire. They induce stress and psychological disorder from shadow flicker, which also has implications for certain types of epilepsy and autism. Even the current planning process, with its virtual absence of consultation, is stress inducing, as is the confrontation between landowners, who wish to profit from erecting turbines, and their neighbours, who dread the effects on their health. Finally, wind turbines considerably reduce the value of dwellings nearby and this has a negative long-term effect on their owners' and their families' health [57]. On top of this, increasing numbers of families will be driven into fuel poverty by spiralling electricity costs which are subsidizing wind energy.

2.4. Controlling Wind Farm Noise

Another aspect is that the instruments and methods used to assess the cut-points may be inappropriate or inaccurate. The United Kingdom's Batho Report of the Noise Review Working Party in 1990 identified [58] low frequency noise as having a serious effect on those exposed to it. It also commented that the use of the A-weighted scale to assess low frequency noise was not appropriate. The A-weighted scale was in fact designed to reflect the normal human auditory range for many common urban/suburban noise sources. The rationale for this derives from work published by Fletcher and Munson [59] in 1933 using pure tones and ear-occluding headsets (headphones) with the object of increasing the distance over which the human voice could be transmitted by telephone wire. The tests were therefore conducted in a setting intended to mimic the use of an ear-occluding headset, *i.e.*, a telephone. The use of occluded ears and pure tones is a totally artificial situation and not directly comparable to "free-field" hearing. Normal hearing occurs in "free field", without occluding the ear, and in the presence of many other background sounds.

When a noise emits more Infrasound and low frequency energy than usual, the use of A-weighted thresholds and measurements is not protective. If unweighted Infrasound measurements had been used to investigate Sick Building Syndrome, its generally accepted cause, Infrasound and low frequency rumble, could have been detected much earlier [60]. It has been known for a long time that fans turning inside buildings can make people sick [61] and there are questions remaining about the effects of even larger fans turning outside buildings [60], *i.e.* wind turbines.

The problem of Infrasound and low frequency noise was well-recognized in a Report by Casella Stanger, commissioned by DEFRA in 2001 [62] with the statement that: “It should not be regarded as formal guidance from DEFRA”, but what is unclear is just when this advice was added. The Report advises, “For people inside buildings with windows closed, this effect is exacerbated by the sound insulation properties of the building envelope. Again, mid and high frequencies are attenuated to a much greater extent than low frequencies.” It continued: “As the A-weighting network attenuates low frequencies by a large amount, any measurements made of the noise should be with the instrumentation set to linear.” It drew heavily upon the Batho Report of 1990 [58]. In fact, these problems had already been elucidated and the measurement issues addressed in a trio of papers by Kelley and his colleagues in the 1980s [63] [64] [65]. Kelley and his colleagues began investigating a single turbine at Boone, North Carolina, in late 1979 when around 12% of families within 3 km where impacted by noise emissions from a single wind turbine. The 237-ft high 2 MW turbine with four cylindrical legs was perched “atop Howard’s Knob” and the passage of the rotors past the legs caused low frequency pressure pulsations to be propagated into the structures in which the complainants lived. The situation was aggravated further by a complex sound propagation process controlled by terrain and atmospheric focusing. The report runs to 232 pages and is certainly comprehensive [64].

The annoyance was described as an intermittent “thumping” sound accompanied by vibrations. A “feeling” or “presence” was described, felt rather than heard, accompanied by sensations of uneasiness and personal disturbance. The “sounds” were louder and more annoying inside the affected homes. Some rattling of loose objects occurred. In one or two instances, structural vibrations were great enough to cause dust to fall from high ceilings and create an additional nuisance. The noise was found to be more persistent and perhaps more severe at night. Moreover, it was noted as being worse in small rooms, usually bedrooms. The impulsiveness of the emitted low frequency acoustic radiation was identified as a major factor in determining not only the level of potential annoyance to residents within a structure, but perception as well. Various recommendations were made concerning noise reduction [65].

Kelley and his colleagues’ research was promoted at conferences on wind turbine noise but seems to have been ignored or forgotten, so the problem continues to be seriously underestimated. When measured using a tool which can detect it, levels of Infrasound and low frequency noise are disturbingly high, with ‘sound pressure levels’ greater than previously thought possible [66]. It has also been demonstrated that infrasonic noise interferes with the micro-mechanics of the human inner ear [67].

In February 2003, the UK Department of Trade and Industry launched [68] ‘Our Green Energy Future,’ which committed the country to wind energy. Despite the existence of the Casella Stanger Report warning about Infrasound and low frequency noise and its caveats about how it should be assessed, the Government used another Report dated May 2003 which told a rather different story [5]. Although a lot more comprehensive than the Casella Stanger Report [62], it was aligned with the ETSU-R-97 recommendations [69] (see below). This is all rather reminiscent of the allegedly "Dodgy Dossier" which the then Prime Minister, Tony Blair, used to launch the UK's involvement in the Iraq war the same year. It was published by the same Government Department which had published the Casella Stanger Report two years before. This looked remarkably like the Government commissioning the report which would facilitate its energy policy.

The Report by Leventhall [5], who has acted as a noise consultant to wind companies, actually states, "The effects of Infrasound or low frequency noise are of particular concern because of its pervasiveness due to numerous sources, efficient propagation, and reduced efficiency of many structures (dwellings, walls, and hearing protection) in attenuating low frequency noise compared with other noise," but it seems that this was the work of a co-writer. Despite this, the message conveyed is that modern wind turbines are not an important source of Infrasound and the use of A-weighting is entirely adequate. The report also states that "Infrasound exposure is ubiquitous in modern life." This may be so, but Persinger makes [6] the point that naturally occurring Infrasound, including that produced within our own bodies, is random, whereas wind turbine Infrasound is pulsatile; and it is this quality which causes health problems.

The message concerning the appropriateness of using A-weighting in assessing sound has recently been reasserted by Leventhall and three of his fellow acousticians [70]. This was in spite of the fact that three of them had previously recommended, in joint and separate statements and publications, that Infrasound should be viewed as a source of adverse effects.

2.5. Wind Farm Guidelines

In the UK, the construction of wind farms is predicated on ETSU-R-97 which was organized by the wind industry, ably assisted by acousticians and others associated with the industry, without a single Sleep Physician, in 1996-1997 [69]. The authors state in the executive summary: "This document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbors, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities." Despite these lofty ideals, a recent review observed [71]: "Exposure to wind turbines does seem to increase the risk of annoyance and self-reported sleep disturbance in a dose-response relationship. There appears, though, to be a tolerable level of around L_{Aeq} of 35dB. " This is about 6 dB less than the permitted ETSU-R-97 night time level, implying a doubling of the setback (assuming a decay of noise level of 6 dB per doubling of distance). The ETSU-R-97 recommendations were based on the turbines of the mid 1990s which had a hub-height of 32 m, whereas today's turbines are several times taller with blades that are much longer and more flexible.

Applying the ETSU-R-97 methodology, which is still in force, setback distances for human habitation from modern 2.5 - 3 MW turbines are in the region of 500 - 600 m. There are good reasons for believing that these setbacks are woefully inadequate. A 2013 Marshall Day Acoustics 'Examination of the significance of noise in relation to onshore wind farms' [72], commissioned by the Sustainable Energy Authority of Ireland, reproduces a graph from the Møller and Pedersen paper of 2011 [73]. This shows how the noise emitted by a turbine increases with size. In fact, a doubling in turbine generating capacity from 1 MW to 2 MW may result in slightly more than a doubling of the overall A-weighted sound power level, that is, an increase of more than 3 dB. Also, for a range of turbines with the same power generating capacity, sound level output can vary by several decibels. Moreover, it was noted that while audible sound increased with increasing turbine size, the emission of low frequency sound was disproportionally greater. Shifting the acoustic energy into the lower frequencies renders A-weighted measurements and guidelines even less applicable. These data applied to turbines up to 3.6 MW, but are expected to apply to even larger ones. It was noted that the relationship is not necessarily statistically significant, which may well be the case, but it is almost certainly biologically significant.

In Ireland, the current setback, introduced in 2006, is a mere 500 m, although there have been repeated promises by government to increase it [74]. There are also concerns about the use of average noise levels as these smooth out the peaks. It is these sound pressure peaks which may be sensitizing people to noise, as has been shown in the case of seals [51]. Averaging only serves to conceal important characteristics which exert adverse effects on living things.

In 2008, the distinguished American acoustic engineers, George Kamperman and Richard James, posed [75] the question: "What are the technical options for reducing wind turbine noise emission at residences?" They observed that there were only two options: i) increase the distance between source and receiver; or ii) reduce the source sound power emission. They added that neither solution is compatible with the objective of the wind farm developer to maximize the wind power electrical generation within the land available. They also highlighted the fact that Vestas' employees are not allowed to go within 400 m of a turbine while it is in motion. Turbines can produce Infrasound even when they are not running when wind excites the tower and blades. Long-range measurements from two different wind farms over a distance of 80 km have shown that Infrasound below 6 Hz has a propagation loss approximating to 3 dB per doubling of distance [76].

Lastly, carpeting the Irish landscape with wind turbines has led to a proliferation in power lines which come with their own health risks. An association between living close to high voltage power lines and the development of childhood leukemia has been consistently observed [77]. Recent epidemiological studies are in agreement with earlier findings of an increased risk of childhood leukemia with estimated daily average exposures above 0.3 to 0.4 μT. Although no mechanisms have been identified and consequently causality cannot be ascribed [77], in view of its serious nature the association cannot simply be ignored.

2.6. What Studies Should be Mounted?

Although the associations between noise pollution, particularly from Infrasound and low frequency noise, and ill health can be argued against, and there are gaps in our knowledge, there is sufficient evidence to cause grave misgivings about its safety. Further research, supported by adequate funding, remains necessary. Good and caring Government should entail acting with greater caution when its policies could jeopardize the Health and Human Rights of its people.

So what studies need to be mounted? Hessler and his colleagues, as well as upholding [70] the adequacy of A-weighting, pose the question: "Do wind turbines make people sick? That is the issue."

This paper, written by four "scientists in the wind turbine acoustical field" who "do not doubt for a moment the sincerity and suffering of some residents close to wind farms and other low frequency sources, and this is the reason all four would like to conduct, contribute or participate in some studies that would shed some light on this issue." This all sounds very laudable, but the basic contention of their paper is that there is no adverse human health effect from low frequency noise and Infrasound, provided that A-weighting is used to measure them and current guidelines are adhered to. What, precisely, qualifies them to pronounce on health issues is obscure.

They continue: "It must also be said that it is human nature to exaggerate grievances and that some qualitative measure must be made available to compensate affected residences." It is hard to assimilate the logic of this sentence, but the first part is clearly intended as an antidote to the residents' "sincerity and suffering" described earlier in the paragraph. It should be pointed out that babies, young children, and animals that are unable to "exaggerate grievances" are also seriously impacted when exposed to low frequency noise and Infrasound, eg badgers [78], pigs [79], crabs [80] and, perhaps, even plants [81]. The phrase "exaggerate grievances" is also redolent of accusing sufferers of hysteria, which is all rather cynical. A similar fate befell Myalgic Encephalomyelitis sufferers when they had their condition derisively dismissed as "Yuppie Flu", until in 2011, when it was finally accepted as a true disease entity and International Consensus Criteria were developed [82].

Some of the studies the "scientists" propose [70] are not particularly scientifically robust: e.g., National Surveys, collecting cross-sectional data which may reveal associations, which, no matter how strong, cannot establish causation, are slow, inconclusive and favor the *status quo*; and Noise Source Reduction, *i.e.* trying to reduce noise emissions from turbines, which seems welcome but oddly similar to the tobacco industry's attempts to reduce tar in tobacco while ignoring the fact that tobacco smoke contains a cocktail of noxious elements [83], as wind turbine noise certainly also does. For example, in addition to Infrasound, Amplitude Modulation related to wake interference between turbines [84] can effectively double the noise produced. This is particularly likely to occur when turbines are crowded too close together, which also reduces their output [85].

Some other suggestions are better such as Perception Testing to investigate whether receivers have the ability to detect a turbine's activity without actually seeing or hearing it. It seems that it is only a minority, albeit a significant one, which is impacted by it. Moreover, whichever pathway transmits Infrasound to the brain is immaterial as it is unquestionably registered there. As noted above, one person who is sensitive to feeling the pulsations has nerve deafness. Furthermore, published reports by acousticians who are sensitive to infrasonic pressure pulses should establish that people can feel them even when sound pressure levels are insufficient to achieve the threshold of audibility [86].

The Recommendation [70] concerning Simulation appears the most sensible, by duplicating and simulating low frequency noise and Infrasound with loudspeakers, and exposing volunteers to high and low levels, to establish threshold levels. This approach would be valid if the sound correctly reflects what is experienced by people exposed to wind turbine noise. Such is the nature of the pulsations that electronic systems employing loudspeakers cannot reproduce them accurately. This all begs the question as to why not carry out this study in the field and measure some hard endpoints?

As the authors point out: "Realistically, it is not even possible to answer the posed question to all parties' satisfaction with practical research. For examples, a direct link to adverse health effects from yesterday's tobacco and today's excess sugar can be denied forever, because any research that could actually prove a link to all parties would take longer than forever and would be totally impractical." Surely there is ample evidence that sugar consumption, as it is a rich source of calories, is associated with obesity? This, although arguably not a disease in itself, is a powerful marker for a range of diseases. In this sense obesity represents a strong "intermediate phenotype" lying on the physio-pathological pathway between health and disease. Similarly, in relation to tobacco, there are biomarkers which are elevated in people who smoke and which indicate an increased risk of lung and other associated cancers [83].

So, does Infrasound and low frequency noise emitted by wind turbines make people sick? The authors comment [70] that, "It is abundantly obvious that intense adverse response occurs at certain sites" but stop short of admitting that it does make people sick, despite their having investigated complaints reported to them by adversely affected citizens. The authors support wind energy: "Likewise, wind farm opponents must accept reasonable sound limits or buffer distance to the nearest turbine—not pie-in-the-sky limits to destroy the industry." This all depends on what is considered "reasonable."

It is abundantly clear that sound levels involve a similar, continuous increase in risk, in a similar way that the amount of tobacco smoked determines [81] the risk of lung cancer. That is why cut-points for the levels of sound permitted were established in an attempt to protect receivers. What we have learned about cut-points in the past, for example from the asbestos scandal, is that, from the outset, cut-points are invariably placed too high and constantly need to be reduced [30].

In the late 18th century, the great Scottish Anatomist, John Hunter, wrote to his protégé, Edward Jenner, asking him: "Why think? Why not do the experiment?" [87]. He was exhorting Jenner to measure the core temperature of a hibernating hedgehog. We all have remnants of the genes for hibernation but we don't express them [88]. Similarly, in common with some animals, we possibly all have the genes for reacting to Infrasound, but only some of us express them.

It would be perfectly feasible to mount an experiment, a randomized crossover trial, in which persons impacted by wind farm noise have their biomarker levels [25] [89] measured after standardized periods of exposure and non-exposure to wind turbine noise. In this way, each person would act as his or her own control. A well-devised trial could be of modest size, be cheap to conduct and deliver results relatively quickly. Assessment of the blood transcriptome [26] would increase the scope of such a trial, as would cortisol assessment [78]. This study could be augmented with the 'Simulation' study proposed by the authors to identify critical frequencies and sound levels if a test chamber and audio system can be devised which accurately reproduces the pulsations experienced in people's homes. Besides, the comparison of means makes for a more powerful statistical analysis. This sort of study will quickly indicate whether exposure to wind turbine noise is safe or not. It has a huge advantage over prospective studies which will take years to accumulate hard disease endpoints, as was the case with tobacco. For many people exposed to industrial wind turbines the question as to whether they can feel or otherwise sense them has already been answered. Could the reluctance of the wind industry to mount the appropriate studies be due to the worldwide spate of complaints from those exposed to wind turbine noise?

The Salford Report, again written [32] by a group of acousticians without any input from sleep experts, concluded that there is "… some evidence for sleep disturbance which has found fairly wide, though not universal, acceptance." The increasing weight of evidence of sleep deprivation's association with several chronic diseases is totally ignored. The authors of the Report are at pains to deny any "direct" health effects. In terms of prevention, any differentiation between 'direct' and 'indirect' is irrelevant: in 271 BC, the Roman consul Manius Curius Dentatus ordered the construction of a canal (*the Curiano Trench*) to divert the stagnant waters surrounding the River Velino in Umbria over the natural cliff at Marmore, to produce Cascata delle Marmore [90]. Romans had an aversion to drinking stagnant water and went to great lengths to "drain the swamp" because they associated it with illness. In this case the stagnant water was only "indirectly causal" but was vital to the propagation of Malaria, and hence draining the swamp abolished Malaria locally.

Governments pursuing renewable energy targets must adhere to the *Precautionary Principle* (see below). They have a duty to commission appropriate studies to ensure that the health of their rural citizens is adequately protected. It might be assumed that the wind industry would have carried out these studies as part of its "due diligence", but, to date, no such studies have been forthcoming.

3. The Public Health Perspective

3.1. Public Health and Utilitarianism

Public Health developed in different ways in different countries. In Europe, Johann Peter Frank's *System einer vollstädigen medinischen Polizey* was particularly influential [91]. Frank's epic work was published in six volumes between 1779 and 1817 and promoted the concept of "Medical Police". The word 'Police' here connotes public administration. It was taken up by Andrew Duncan (Senior) in the Edinburgh University Medical School, who published a "Memorial" in 1798 presenting an outline of what he saw as a comprehensive course of instruction in Medical Police [92]. The concept spread to Ireland, where Henry Maunsell was appointed as Professor of Political Medicine at the Royal College of Surgeons of Ireland in 1841 [93].

The concept was also adopted in England, where Edwin Chadwick wrote upon Preventive Police in 1829 [94]. Chadwick was a lawyer and "…'the bureaucratic radical'… disciple of the archutilitarian [sic] Jeremy Bentham," who in 1842 was to publish his famous *Report on the Sanitary Conditions of the Labouring Population of Great Britain*, which he wrote in his position as Secretary to The Poor Law Commissioners. As a young man, Chadwick was Bentham's assistant and he afterwards applied Bentham's Utilitarian principles to Public Health [95]. Chadwick's *Report* paved the way for the establishment of the General Board of Health in 1848, under the great Public Health Act [96]. Chadwick's work heading the Board strongly influenced the thinking of doctors such as John Simon, and this marks the birth of Public Health in England [96] and the Medical Officers of Health. Thus, in Britain, modern Public Health grew out of the Utilitarian philosophy, developed by Jeremy Bentham, which enshrined the ethos that a morally good action is one that helps the greatest number of people.

However, it now seems that economic growth, particularly during a recession, is such an important goal that other aspects, such as health, are seen as being of secondary importance. It is essential that Public Health should increase its vigilance; to do any less would be to betray its proud past.

3.2. Collateral Damage

In the United Kingdom in1853, a Vaccination Act was passed: it was a *compulsory* act which decreed that all parents had to have their infants vaccinated against Smallpox within three months of birth. It supplanted the *permissive* Vaccination Act of 1840, which simply hadn't worked. Although it was known that a small proportion of children would succumb to the effect of the vaccination, this was trifling in comparison to the number of deaths from Smallpox which would be prevented [97]. In effect, Public Health had accepted the principle of *Collateral Damage*, provided that the overall benefit was large and the damage was small. Eventually, by the 1970s, vaccination was phased out because as the eradication of Smallpox approached, vaccinia was claiming more lives than Smallpox was [98].

3.3. The Precautionary Principle

The problem is just how much *Collateral Damage* is acceptable? When the BSE epidemic emerged in the late 1980s, the Government insisted that, providing simple measures were applied, beef was perfectly safe. The Minister of Agriculture went public and was photographed administering a hamburger to Cordelia, his four-year-old daughter [99]. Instead of applying the *Precautionary Principle* (enabling rapid response in the face of a possible danger to human, animal or plant health) [100], which should have triggered primate feeding experiments, the Government decided to tough it out, apparently for the health of the Farming Industry rather than for the health of its citizens. It compromised by having neural tissue separated from meat, seemingly oblivious of the fact that nerves innervate muscle. In effect, the experiment was being carried out on an unsuspecting populace.

In 1996, the first vCJD cases were identified and epidemiologists predicted thousands of deaths. Public Health was remarkably quiet on the issue but, to date, the disease has only resulted in 177 deaths. The reason that it has not been higher lies in the fact that there is a very specific genetic element as to who will develop the disease. There were no long-term monitoring measures put in place, but *ad hoc* studies indicate that the number of people infected with abnormal prion protein may be in the region of 30,000 [101]. Although representing only a small proportion of the total population, it still lies uneasily with Utilitarian principles in that the level of possible *Collateral Damage* was unacceptably large.

A similar population experiment seems to be underway in terms of environmental noise pollution. Governments, faced with economic recession, have been keen to increase economic activity and meet Green targets. As a result, environmental noise has increased. Public Health must maintain its position as champion of the health of the public and not just slavishly back up government policy. How can it be that environmental noise pollution continues to escalate despite the very real adverse effects it exerts on human health? A recent report from the Royal Society of Public Health has placed stress [102] on the importance of sleep to health. This is all very well, but nowhere in the 30-page document is there a mention of the role of noise in disrupting sleep, in fact the word "noise" is completely omitted. Perhaps the Royal Society was anxious not to open the noise can of worms? In her 'Notes on Nursing' in 1859 [103], Florence Nightingale was not so squeamish, because when she extolled the importance of sleep to health, she was also attuned to the deleterious effects of noise: "Unnecessary noise…is the most cruel absence of care which can be inflicted either on sick or well."

As sleep deprivation is the most important health-damaging effect of environmental noise pollution, Public Health should be treating the matter very seriously. Indeed, the United Nations Committee Against Torture (UN CAT) has explicitly identified "sleep deprivation for prolonged periods" [104] as a method of torture. In 1978, in a case taken to Europe by the Irish Government, the British Government was found guilty of applying five techniques, including subjection to noise and deprivation of sleep [57]. These were used in Ulster to 'encourage' admissions and to elicit information from prisoners and detainees. They amounted to humiliating and degrading treatment, *i.e.* torture. Although the judgment was afterwards overturned on appeal, and downgraded to 'inhuman or degrading treatment', the action is still alive. The case being taken by 'The Hooded Men' is being backed by the Irish Government [105]. This same Government, by its failure to revise the turbine setback guidelines, is imposing noise and sleep deprivation on its rural citizens.

3.4. Public Health's Responsibilities

When Public Health doctors are asked about possible health effects, they tend to dismiss the literature as either non-peer-reviewed, or if it is a review, non-systematic. If they want to read a comprehensive, thorough and systematic review, they should look no further than that by Punch and James [106]. The Public Health Agencies in the UK are now relying on a document published in April 2013 which is also not peer-reviewed [32]. As already mentioned, was written by a group of acousticians at the University of Salford, which begs the question as to why such a group was selected to pronounce on health issues. Since acousticians derive a significant proportion of their income from the wind industry, their scientific objectivity might be open to question. Similarly, if a profession which worked closely with the tobacco industry was asked to report on health, questions would be asked.

Recently, a Vestas PowerPoint presentation from 2004 has surfaced [107] demonstrating that Vestas knew over a decade ago that safer buffers were required to protect neighbors from wind turbine noise. They knew their pre- construction noise models were inaccurate and that "...we know that noise from wind turbines sometimes annoys people even if the noise is below noise limits." Similarly, we are repeatedly told that modern turbines are quieter and produce less Infrasound and low frequency noise, which in reality is the reverse of the case. Denmark has been in the vanguard of wind energy development and there is a Danish initiative entitled "WIND2050" [108]. This appears to seek to promote the interests of the wind industry, particularly through encouraging "Community Ownership" of wind farms. To enable this, the project is "mapping criticism", *i.e.* assembling maps to show where rural citizens have raised any objection to wind farm development. It seems analogous to tobacco companies keeping smoking cessation clinics under surveillance.

There has been a tendency for Public Health to toe the official line that wind farms are entirely safe. This is the message promulgated by the wind industry so Public Health should be evaluating the evidence more critically. If Public Health doctors actually visited the families who have been forced to abandon their homes they might demand to see the necessary studies conducted. They would learn that some of the worst affected are small children who are very often put in the smaller bedrooms which are worst impacted by noise [64]. There is also the intriguing possibility that if Infrasound is conducted through the skin [54], young children will receive a larger dose because their surface area is greater in relation to their volume in comparison to adults. This is why small children lose heat faster than adults.

To her credit, in 2014, one Irish Public Health doctor, the Deputy Chief Medical Officer, actually stated that while turbines do not represent a threat to Public Health, "there is a consistent cluster of symptoms related to living in close proximity to wind turbines which occurs in a number of people in the vicinity of industrial wind turbines" and that "These people must be treated appropriately and sensitively as these symptoms can be very debilitating" [109]. The Irish Wind Energy Association promptly rounded on her with the accusation of her "having focused on out-of-date information," but she stood her ground admirably.

In view of the foregoing considerations, and because Public Health's apparent official view is that there are no important health effects caused by exposure to wind turbine noise, a reappraisal of the evidence is overdue. Public Health doctors should be conducting focused epidemiological studies, but this is something that they haven't displayed much aptitude for of late. Apart from anything else, Public Health should be rigorously applying the *Precautionary Principle* or *Primum non nocere* (First, do no harm) ideal, putting monitoring and evaluation in place and then undertaking the appropriate studies. A recent review of peer-reviewed studies published between 2000 and 2015 concluded [110] that the estimated pool prevalence of high subjective annoyance was around 10%. This figure is very close to that found by Kelley [64] and his colleagues cited above, although the true figure may well be higher. The authors observed that epidemiological research on low frequency noise is scarce and suffers from methodological shortcomings. They added that low frequency noise in the everyday environment is an issue which requires more research attention, particularly for people living in the vicinity of relevant sources.

Environmental noise pollution, particularly when it deprives people of sleep, is especially related to the development of CVD, as a recent paper concluded that: "... the public health impact of sufficient sleep duration, in addition to the traditional healthy lifestyle factors, could be substantial" [36]. Public Health must take its responsibilities seriously to protect the Health and Human Rights of all citizens. Despite a desire to meet various Renewable Energy targets, Government must ensure that the appropriate studies are undertaken in order to protect the sizeable minority of the exposed population which suffers adverse effects. In fact, Jeremy Bentham shrewdly anticipated the necessity for Government support for research in both theory and practice [111]. In the 19th century, Public Health acted to protect the health of town dwellers, thrown together by the Industrial Revolution. People had moved from the country into towns where they were exposed to industrial pollution. We are now witnessing the reverse process, a second Industrial Revolution, in which large industrial machines are being imposed on rural dwellers, and Public Health must act to see that sufficient safeguards are put in place so that rural citizens' health is fully protected.

As Bradford Hill observed [112] over half a century ago: "The lessons of the past in general health and safety practices are easy to read. They are characterised by empirical decisions, by eternally persistent reappraisal of public health standards against available knowledge of causation, by consistently giving the public the benefit of the doubt, and by ever striving for improved environmental quality with the accompanying reduction in disease morbidity and mortality". Quite so, it is high time that Public Health gave the public the benefit of the doubt.

4. Conclusion

So has Public Health become too utilitarian? All the available evidence indicates that an important minority of local inhabitants is severely impacted by noise emitted by wind farms sited too close to their homes. This degree of *Collateral Damage* is too large to accept in terms of Utilitarianism. Public Health must exercise the *Precautionary Principle* and retain as much independence from government as possible in assessing the health effects of national policies. The Health and Human Rights of rural-dwelling citizens are every bit as important as those of the rest of society. In fact, in terms of wind energy, the overall benefit is fairly modest [113] [114] and the adverse effect on people's health is far from small. It is essential that separation distances between human habitation and wind turbines are increased. There is an international consensus emerging for a separation distance of 2 km; indeed some countries are opting for 3 km and more. Furthermore, the appropriate, focused studies should be undertaken as soon as possible.

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