Assessment of appeal documentation relating to the impact of the Dersalloch Windfarm on the Scottish Dark Sky Observatory

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1 Introduction

The Scottish Dark Sky Observatory (SDSO) sits in the Craigengillan Estate (at N 55° 17.465′, W 4° 24.279′), at the northern end of the Galloway Forest Dark Sky Park (DSP). The Park has been awarded Gold-Tier status by the International Dark Skies Association. This is a prestigious award, and the site has been strongly promoted by local councils as an amenity for tourists interested in seeing a truly dark night sky and for more serious amateur astronomers interested in using the site for deep-sky observing.

ScottishPower Renewables (UK) Limited (SPR) has proposed the construction of twenty three wind turbines on Dersalloch Hill which are, at their closest, 4.9 km from the SDSO site. Thirteen of these turbines must be fitted with infrared LED warning lights, invisible to the unaided eye but visible to military pilots using night vision equipment.

In this report I assess the response of SPR to concerns that the development will have a detrimental effect on SDSO and the DSP. I limit this assessment to factors that could directly affect observational astronomy at the site and its Gold-Tier status, and ignore any other aesthetic concerns. The report is similar to one I supplied to East Ayrshire Council on the impact of the Burnhead Windfarm on SDSO and DSP, and I have made parallel assessments to that report where appropriate.

I am Professor of Astrophysics at the University of Glasgow, head of the Astronomy and Astrophysics Group in the School of Physics & Astronomy and Director of the University Observatories. My background is in observational radio astronomy and observational gravitational-wave astrophysics. I am familiar with the equipment and techniques used in amateur optical astronomy through the University Observatories where we use many pieces of equipment for undergraduate teaching that were originally designed for the amateur market. My background in gravitational-wave astronomy is pertinent to the assessment of seismic noise.

2 Assessment of the Lumsden Report

Dr Stuart Lumsden (University of Leeds) is a highly-respected professional astronomer whose research expertise in infrared observational astronomy puts him in a excellent position to advise on the matters in hand. His detailed report[1] considers the relevant factors that could make infrared lighting problematic for SDSO and the DSP, and his overall conclusion is that the lighting should not be a matter of concern for astronomy. Though my quantitative estimates of the brightness of the infrared beacons differs somewhat from those in his report I am in broad agreement with Dr Lumsden's conclusions.

[1] Lumsden, S., *The Impact of Infrared Military Aviation Lights at Dersalloch Windfarm on Galloway Dark Sky Park.*

These issues are the focus of the SPR Dersalloch Windfarm 2012 ES Addendum *Response to South Ayrshire Council Objection* February 2013 section 2.2, to which the Lumsden Report is Technical Appendix A.

2.1 Impact on Gold-Tier status

Gold-Tier Park status is based on the level of light pollution in the *visible* part of the spectrum. The proposed lighting is claimed to be purely infrared and therefore is not a factor in the assessment of Gold-Tier status. The LEDs used in military aviation lights (Appendix B to Lumsden's report, Contarnex CEL-IR850-024-CST) emit mostly at wavelengths between 800 and 900 nm. I could not verify the spectral shape shown in Appendix B, but it looks typical of narrow-band 850 nm LEDs. Dependent on the spectral leakage into the visible band this *may* appear as (at the most) a very dim cherry-red glow, but certainly this will fall far below the levels relevant for Gold-Tier status. My enquiry to the manufacturer (Contarnex Europe Limited) confirmed that there is some visible red emission from these lights, but at a low level. It is difficult to say whether it will be visible from SDSO without an experiment, so one might want to view an installed unit to verify that any residual glow is not discernable to the dark-adapted eye if this is a concern. I note that Contarnex also supply infrared aircraft warning lights with additional red LEDs (CEL-IR850-R-024-CST). Clearly these versions should be avoided.

2.2 Impact on infrared astronomy

Although the infrared lighting falls outside the band relevant to Gold-Tier status, it falls *inside* the sensitivity band of specialised cameras used by amateur astronomers. This will not be a concern to the majority of people enjoying the dark skies that the site provides, but it is a potentially troublesome factor for the better-equipped amateur or indeed for SDSO itself. Dr Lumsden considers the brightness of the infrared beacons in comparison to other sources of infrared light, including local settlements, stars and planets.

He concludes that all thirteen of the infrared lights will be directly viewable by the 20-inch telescope at SDSO, and all will lie above the visible horizon. My calculations indicate the visible horizon, to the west of SDSO where the turbines will appear, is approximately 1 degree above the true horizon, and the turbine hubs will be up to nearly 1 degree above that (assuming a hub height of 80 m). Importantly he also concludes that there is no direct line-of-sight to any of these LED lights from the ten other designated 'potential viewing sites' identified by the DSP's website.

I agree with these results, and do not believe that direct illumination from these lights interferes with reasonable astronomical observations. One possible exception to this may be fish-eye images of the entire sky sometimes used to assess cloud cover and for all-sky monitoring observations of phenomena such as meteors. These observations are often performed with CCD cameras that would be sensitive to the infrared emission for the lights, and bright point sources in the periphery of the field could be a minor nuisance. I also believe they will be somewhat brighter than Lumsden estimates. His calculation here is a little unclear: on page 3 he states that "only about one eighth of the emitted light, or about 3 W, would be visible from a given location to a suitable infrared detector". This statements lack some clarity so I have re-analysed the data here.

The infrared units are specified as each taking less than 13 W of electrical power so, assuming a conservative estimate of efficiency, I would expect something like 3–5 W of infrared light emitted per unit, and therefore about 40–65 W of infrared light overall (without a correction for intermittency). To put this in perspective, it is the equivalent of the infrared emission (i.e, between 800 and 1000 nm, and not visible) of a single, 400 W halogen security light. My own calculations below uphold the general conclusion that the lighting is not problematic to amateur astronomers.

Although visual emission is negligible, the wavelengths of these lights fall within the pass-band of 'I-band' astronomical filters. This band is little-used by amateurs, but the lights will appear as a constellation of point sources, just above the visible horizon from SDSO. They will be brighter than anything in the sky at these wavelengths and will be apparent to many dedicated astronomical CCD cameras, though I stress again that these will *not* appear that bright to the naked eye. Each light is specified as 600 mW sr^{-1}, implying a flux of 6×10^{-7} W m^{-2} at a distance of 1 km and 2.5×10^{-8} W m^{-2} at SDSO, 4.9 km from the closest turbines. An amateur using a UBVRI I-band filter ($\lambda = 880$ nm, $\Delta\lambda = 240$ nm) will see this as a source of effective I-band flux density of 10^{-7} W m^{-2} μm^{-1}. This is equivalent to a star of magnitude -2.7 (taking $m_0 = 8.3 \times 10^{-9}$ W m^{-2} μm^{-1}). I-band magnitudes for stars are not routinely available, but I would put this very much at the top end, probably brighter than any star or planet. It should also be noted that these 'stars' will appear against the sky, above the local horizon. However they are at a low elevation (approximately 1°) and will therefore not interfere with routine infrared astrophotography from SDSO which is made at elevations much greater than this.

Dr Lumsden also considers the potentially more problematic issue of scattered light from the turbine LEDs. He uses the modelling method of Garstang (Garstang R.H., PASP, 98, 364–375, 1986) to calculate the scattered light, and concludes that (page 6):

> "The calculated sky brightness for all parts of the sky [due to scattered light from the turbine LEDs] lie well below the natural sky brightness in the I-band (750 nm–900 nm)."

I have not checked these calculations in detail, but the result appears reasonable. Based on the numbers he gives on page 3 of the report I believe he has somewhat underestimated the power output of these LEDs, but the contribution of the lights to skyglow will still be minimal. He also correctly states that the infrared emission from Dalmellington and other towns will greatly exceed that of the turbine lights.

2.3 Overall assessment

Overall, I find Dr Lumsden's assessment of the impact of the thirteen infrared turbine lights located on Dersalloch Hill on the Gold-Tier status of the DSP, and on practical astronomical observations at SDSO, to be fair and balanced. Although I quibble over precise numbers I agree with his conclusion that the effects of the lights are negligible in comparison to natural and man-made infrared emission and are well below a level that could be reasonably thought of as problematic to amateur astronomers. As stated several times, the issue of Gold-Tier status is moot, as it concerns only visible light. Any residual visible red light from the LEDs will be dim, but *may* be visible. The physical presence of wind turbines on the westerly horizon close to SDSO could be an aesthetic distraction, but the lighting should not damage observatory operation.

3 Turbulence and ground vibration

Although not addressed in the Lumsden report, air turbulence is a potential worry for the SDSO telescope performance. The remarkable (and possibly exceptional) image in Fig. 1, shows the turbulence, mixing and condensation trail of the Horns Rev 1 windfarm off the Danish coast. An astronomer downwind of this turbine array will certainly get a worse view of the sky than one upstream, if only because it is foggier.

Less obviously, the effect of wind-turbine-induced turbulence on astronomical 'seeing' (the random atmospheric refraction that degrades the angular resolution of a telescope and makes stars 'twinkle') may degrade the performance of SDSO instruments and has not been investigated in the literature to my knowledge. Although a background concern, currently I know of no strong quantitative assessment if its importance. However we may expect uniformly flowing air (from, for example, the sea) to become more turbulent as it passes structures on land such as trees hills and windfarms, and the prevailing westerly winds would push any turbulent wake from Dersalloch towards SDSO.

In addition to the possible effects of turbulence one might also consider the relevance of ground vibration from the turbines. It is difficult to set a general level of ground vibration that would be problematic to an observatory. To a large extent the response of a telescope to ground vibration is

Figure 1: Turbulence patterns revealed by the condensation wake of the Horns Rev 1 offshore windfarm. Photographer Christian Steiness, (Credit: Vattenfall) . http://ict-aeolus.eu/about.html

a function of the resonances in the telescope's own structure. However, it would be unreasonable to complain if the noise spectral density from the turbines fell significantly below the background level already present at SDSO at all frequencies. This may indeed be a very conservative upper limit to acceptable level of vibration. The true limit may be considerably higher, and it is rare for small observatories to be troubled by ambient ground vibration if properly built.

We can crudely estimate the level of ground displacement that would affect a telescope by neglecting both resonances and finite rigidity and allowing the telescope to swing around its centre of mass by an angle of only 1 arcsecond in response to ground movement (the level of excellent astronomical seeing). For a 2-metre-tall telescope this corresponds to a horizontal ground displacement of about $5\,\mu$m. We note here that a perfectly rigid telescope fixed to the ground is not affected by horizontal motion at any level, and that any effects are strongly attenuated above the natural swing frequency of the telescope so, resonances aside, the true acceptable level of motion is probably much greater then this.

A deep investigation of the seismic effects of windfarms has been carried out by Styles et al. 2005 (Microseismic and infrasound monitoring of low frequency noise and vibrations from windfarms[2]) in relation to their impact on the Eskdalemuir Seismic Array. They conclude that turbines generate signals that can be detected several kilometres away, but these are concerns for a sensitive seismic station rather than an astronomical observatory.

An earlier investigation on the impact of the Stateline Wind Project on the LIGO gravitational wave detector, with which I am very familiar (Schofield R., LIGO internal report LIGO-T020104-00-Z[3]), found that the strongest seismic peak (at 4.3 Hz) could be seen 18 km from the turbines but with a ground motion spectral density of only $0.7\,\mathrm{nm\,Hz^{-1/2}}$. Although relevant to LIGO, this is at a level several thousand times less than the $5\,\mu$m rms estimate for the threshold of concern above, so the evidence to hand indicates that the Dersalloch windfarm would not generate seismic disturbances at a level that would be noticeable to SDSO.

[2] www.keele.ac.uk/geophysics/appliedseismology/wind/Final_Report.pdf

[3] https://dcc.ligo.org/LIGO-T020104-x0/public

4 Summary

I find that the overall impact of infrared turbine lights, as specified by the MOD, has been fairly assessed in the Lumsden Report and that it should not be a concern to the DSP or SDSO. The infrared lights may be visible to the unaided, but dark-adapted, eye as a dim red glow, but their brightness would not be sufficient to affect Gold-Tier status. The lights will appear up to nearly a degree above the local horizon, as seen from the SDSO site, but this it too low an elevation for them to be a general concern, even for infrared astro-photography. Scattered infrared light from the beacons has also been fairly assessed, and this again is not a concern. The effect of ground vibration depends on many variables and is harder to quantify, but simple calculations indicate that there is no cause for concern here either. The effect of turbine-induced air turbulence on astronomical 'seeing' may be a concern. However we simply do not know if wind turbines significantly degrade the performance of telescopes downwind, and without good evidence to the contrary I would not regard it as a deciding factor in the overall assessment. No assessment of the current seeing conditions at SDSO has been presented, and seeing is affected by many other factors, such as natural thermal mixing and local topography. In my opinion there are too many uncertainties here for this to be elevated to more than a worry, but practical research in this area is clearly needed.