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David MacKay's book:
Sustainable Energy Without the Hot Air

An Environmental Transport Engineer's Assessment

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Last year I exchanged several emails with David MacKay, now the Chief Scientific Adviser to the Department of Energy and Climate Change, alerting him to various problems with the Internet version of his popular and widely acclaimed book 'Sustainable Energy Without the Hot Air'[1]. Since then it has been published in print without any major changes.

Although the book provides some useful insights and contains some good ideas, the anti-green lobby have had a field day with some of its implications! One misinterpretation arose from a section in the book on wind that grossly underestimated the energy available from wind-farms in relation to that necessary to power cars. In view of the ability of battery electric cars to store intermittent sources of energy, it is vitally important to provide an accurate and clear message to the public on the potential of wind in powering our transport fleet.

MacKay states: *"Let's be realistic. What fraction of the country can we really imagine covering with windmills? Maybe 10%? Then we conclude: if we covered the windiest 10% of the country with windmills (delivering 2W/m2), we would be able to generate 20 kWh/d per person, which is* ***half*** *of the power used by driving an average fossil-fuel car 50 km per day. Britain's onshore wind energy resource may be "huge," but it's evidently not as huge as our huge consumption"*

However, MacKay bases this "power" figure on the chemical energy in the fuel, prior to all the losses in the engine and transmission, neither does he allow for the energy required to refine the fuel! It is therefore grossly misleading to compare this chemical energy with wind power or electricity due to the different energy paths, losses and potential for supplying useful work at the wheels of a car in either case. By some estimates petrol fuel has a "well to wheel" efficiency of only 13% over realistic driving conditions.[2] In contrast, a wind farm can generate high quality energy in the form of electricity which can be converted to a "well to wheel efficiency" for an electric car (after allowing for the wind turbine power factor) of around 50-60%.[3]

In fact, using these efficiencies we would need to cover only about 2.5% of the UK with wind turbines to generate the equivalent power at the wheels as *20 kWh/d per person* of

[1] David MacKay: Sustainable energy without the hot air 2009
[2] a comparison of technologies for carbon-neutral passenger transport Johansson & Ahman (2002)
[3] "Electric vehicles can be about **four times as energy-efficient** as standard fossil-fuel vehicles" re: from MacKay's own literature http://www.publicservice.co.uk/feature_story.asp?id=11786

fossil fuel energy would, using electric vehicle technology. This is based on the wind power densities and other assumptions MacKay uses.

However, why not just be clearer as well, and calculate what land area of wind turbines would be necessary to power the entire UK car fleet through electricity? Using MacKay's assumptions of wind power density, annual fuel consumption data[4], and a DfT paper[5] on the grid demand for replacing the fossil fuelled car fleet with electric vehicles, only 1.5% of the UK area is necessary, not much more than that of the Outer Hebrides.

That is not all, MacKay's calculations use wind speeds in town locations at about a tenth of modern wind turbine heights and includes various rounding errors which increase the required land area even further. Using the performance of the most efficient turbines and wind speeds on the Isle of Lewis[6] the area could be *potentially* reduced further to about 0.5% of the UK, indeed about the area of Lewis itself.

A spreadsheet is provided here for the calculations and sources, which can be downloaded here if the user wishes to enter different assumptions.[7]

The second issue that concerned me was the section in the book on aircraft efficiency and turboprop engines in particular.

MacKay says **"***Aren't turboprop aircraft* far *more energy-efficient?* **No.** *The "comfortably greener" Bombardier Q400 NextGen, "the most technologically advanced turboprop in the world," according to its manufacturers [www.q400.com], uses 3.81 litres per 100 passenger-km (at a cruise speed of 667 km/h), which is an energy cost of 38 kWh per 100 p-km. The full 747 has an energy cost of 42 kWh per 100 p-km"*

This technology comparison was apparently based on comparing just two aircraft with a twenty-fold difference in weight; each built to cope with widely different operational requirements! Whilst it is true that the energy advantage of modern turboprop aircraft over regional jets has been gradually eroded over the years, reputable data suggests that turboprops still use at least 10%[8]-20%[9] less fuel per passenger seat than jets over short routes.

Even if turboprops were no more efficient than jets, they provide higher low speed thrust, allowing aircraft to use shorter runways, a wider range of airports, and achieve greater airborne and ground efficiencies due to their ability to accelerate faster. Overall, this achieves significant fuel consumption benefits for all aircraft by allowing the air space to become generally less congested and operational efficiencies to be higher. Surely this is important considering the commercial pressure to build new runways and airports?

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[4] See Section 3.1 Petroleum consumption: by transport mode and fuel type: United Kingdom: 1998-2008

[5] DfT 2007, Low Carbon Transport Innovation Strategy, Potential importance of a low carbon electricity mix, Section 9.12 http://www.dft.gov.uk/pgr/scienceresearch/technology/lctis/lowcarbontis?page=12#a1061

[6] personal communication with chief engineer of Lewis windfarm, and other sources quoted in spreadsheet (ref 7)

[7] http://www.entrans.co.uk/Power%20from%20turbines%20windmill%20area.xls

[8] http://web.mit.edu/aeroastro/people/waitz/publications/Babikian.pdf

[9] http://www.theicct.org/documents/ICCT_Aircraft_Efficiency_final.pdf

Unfortunately, turboprop non-fuel costs are generally higher than jets; and are potentially less popular with passengers having lower cruising speeds; hence they are only used over the shortest routes. Aviation fuel tax policy combined with changes in public attitudes could have an important influence encouraging their use in favour of jets.

The greatest environmental advantage of turboprops however, is their vast potential for reduced greenhouse gas emissions. Elsewhere in the book MacKay makes a brief excursion from energy calculations by mentioning that the emissions released from aircraft may contribute 2.5-3 times to global warming than their carbon emissions alone, due to the high altitude they are released at. However, he doesn't mention that turboprops operate at a relatively low altitude where this effect doesn't apply. Even for a book focussed on energy consumption this is an important omission.

This illustrates the weakness of using energy metrics to formulate policy. We can rarely justify reducing energy for its own sake but for some higher purpose such as cost, environmental protection or conservation of supplies, therefore policies have to be formulated with reference to these criteria! Since aviation is the fastest growing source of transport greenhouse gases and the greenhouse gas forcing is estimated to be 2-3 times as much as the carbon emissions, the environmental aspects should have priority in this case. Although avoidance, partly through telecommunications is the best option to control aviation emissions, for those who need to fly there seems to be a clear choice here between the lower emissions of turboprops and the faster jets.

Finally MacKay makes the dubious claim that *"No redesign of a plane is going to radically improve its efficiency."* This is a brave prophecy, since it implies a technical conspiracy within the aircraft industry. These are just some of the improvements being claimed by them: 6% to 16% for contra-rotating propellers,[10] 20% for carbon fibre material in the wings,[11] and 30% for blended wings[12]. The combination of these initiatives alone have the potential to reduce fuel consumption (depending on how these were originally defined) by something like 40-50% and greenhouse gases if using a low altitude turboprop rather than jet by perhaps 75-80%, a substantial amount!

Stephen Latham, December 2009

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[10] http://aaronbeekay.net/EE%20First%20Draft.pdf
[11] http://www.crunchgear.com/2008/06/26/carbon-fiber-used-in-wings-of-new-airbus-a400m/
[12] http://www.nasa.gov/vision/earth/improvingflight/x48b.html