Regarding: 'Solar Energy in the context of energy use, energy transportation, and energy storage', by David J.C. MacKay, FRS.

1) The author states: 'The areal power density is uncomfortably similar to the average power density that could be supplied by many renewables:'.

Could the author comment on: This takes the present power consumption as given, which was not the case in the past nor necessarily would be in the future. Given the mission, engineers have usually delivered within factor 2 of the thermodynamic limit. Yet the state of the art is within factor 2 of the minimum for only a few end uses and the practice is far from it for most. For example, for white light, where the thermodynamic minimum is about 330 lm/W, the state of the art is from 150 to almost 250 lm/W. (http://en.wikipedia.org/wiki/Luminous_efficacy and http://iopscience.iop.org/0022-3727/43/35/354002/ ). However deployment is another matter. For lighting, this is helped by the short lifetimes of existing incandescent lamps, and is also backed by legislation. Conversely, pumps, fans and compressors (e.g. in refrigeration and air conditioning equipment) operate far from the thermodynamic minimum, particularly those that lack variable speed drives (VSDs). Power varies as the cube of the speed in the ideal case, and can approach this in practical cases. So for these end-uses there are known solutions, already produced in some volume, but little deployed as yet. That said, legislation is appearing in some markets, such as the EU.

This statement also takes no account of energy quality or exergy. According to the Second Law of Thermodynamics, an amount of electricity has far more work potential than an equal amount of heat at a temperature of say 70 C. Yet the latter has quite sufficient exergy for space and water heating, which accounts for about 50% of final energy in the UK. Such exergy-matching particularly affects the scope for cascading of energy from one process to another, giving multiple use. (see below).

The ETH (The Swiss Federal Institute of Technology), with PSI, WSL, EMPA and EAWAG, published in English in 2002 a pre-study entitled 'Steps towards a 2000 Watt-Society'. (http://efficientpowersupplies.epri.com/pages/Steps_towards_a_2000_WattSociety.pdf ). This was followed in 2004 by 'Steps towards a sustainable development: A White Book for R&D of energy-efficient technologies'. (http://www.novatlantis.ch/fileadmin/downloads/2000watt/Weissbuch.pdf ). The latter found: 'First empirical and theoretical considerations suggest that the overall energy efficiency of today's industrial economies could be improved by some 80 to 90 % within this century (e.g. Jochem et al. 2002). Given the above-mentioned challenges connected with energy use and the high potentials for efficiency improvements, the Swiss Board of the Federal Institutes of Technology (1998) promoted the vision of a 2000 Watt per capita society by the middle of the 21st century. This represents a reduction of present Swiss per capita primary energy use by two thirds'.

So what might be seen as a constraint at 5000 W/capita would be far less so at 2000 W/capita – a factor of 2.5 x.

2) Could the author comment on: The estimation of the areal (annual average) power densities for wind turbines is wanting:

While wind turbines must be spaced several diameters apart in both directions to maximise the yield per wind turbine, the towers themselves occupy only of the order of 1% of the area. So farmers can continue to grow crops and raise livestock on almost all of their land, while harvesting a valuable additional crop from the wind. On this view, the areal power density of wind turbines is greater by about 100 x.

For offshore wind farms, the land area required is limited to the transmission corridors, where again farming can continue underneath the transmission lines. Moreover all the remaining nuclear power plants in the UK are coastal, so upon their closure the grid connections could be re-used for offshore wind farms.

Furthermore, the annual average capacity factor of offshore wind turbines is already around 0.40, and could be 0.50. (http://energynumbers.info/capacity-factors-at-danish-offshore-wind-farms and http://www.energy.siemens.com/fi/en/power-generation/renewables/wind-power/offshore.htm ). Compared with that for onshore wind turbines of about 0.25, with a range from 0.15 to 0.40, this is about 1.8 x. (http://www.ref.org.uk/roc-generators/ ). This factor would apply to any areal power density for wind turbines, whether based on the land corridor or the sea area.

The area available for UK offshore wind farms with fixed wind turbines is large. (http://www.bwea.com/pdf/publications/Round3_announcement.pdf p 9). However, floating wind turbines are being demonstrated at full scale by Statoil, with Siemens and others. (http://www.youtube.com/watch?v=06D4LvU-CG8 , http://www.statoil.com/en/TechnologyInnovation/NewEnergy/RenewablePowerProduction/Offshore/Hywind/Pages/HywindPuttingWindPowerToTheTest.aspx and http://www.pressherald.com/news/interest-of-wind-farm-company-runs-deep_2012-06-15.html). So in principle, wind farms could be deployed over the whole Exclusive Economic Zone (EEZ) of the UK. (http://en.wikipedia.org/wiki/Exclusive_economic_zone#United_Kingdom ). This has an area of 773,676 km2, which – compared with the area of the UK at about 245,000 km2 – is 3.15 x. While this factor does not directly affect the power density per unit area of the UK EEZ, it increases the potential power per unit land area and thus per capita of the UK. Moreover, deployment of wind turbines within the UK EEZ has obvious advantages over deployment of e.g. solar electric plants and power lines in foreign lands, which would always be at risk from terrorism, sabotage and nationalisation.

3) The author suggests that: 'Several other high-density, high-consuming countries are in the same boat as Britain, and many other countries are rushing to join us'.

Could the author comment on: Neither are necessarily the case. Countries in Continental Europe and such as China, India and Russia have a greater awareness of the engineering potentials within the scientific laws, such as the Second law of Thermodynamics, and on energy services. Hence they focus on not heat but thermal comfort and on not electricity but illumination, fluid transport etc. They are thus more likely to converge well below Britain's present level of final energy per capita, while enjoying similar levels of end-use service. Moreover, this will happen because it is consistent with the scientific laws and hence the engineering potentials (see the ETH pre-study above) and for reasons of international competitiveness.

4) The author brackets together 'radical efficiency measures and lifestyle changes;'.

Could the author comment on: However, these are not necessarily linked – rather the opposite. As the real cost of energy rises, wasteful users like Britain today will be less able to pay and forced to use less through lifestyle changes. Conversely, those countries that act on the thermodynamic potentials will enjoy today's standard of living at far lower energy and monetary costs.

In reality, Britain is not an independent agent, since much of it's end-use equipment, both domestic and industrial, is bought from abroad. Over time, as equipment is replaced, each new generation will consume less and less energy – notably electricity - as they approach within factor 2 of the thermodynamic limit. Moreover, end-use equipment such as domestic appliances, is typically replaced after shorter periods (e.g. 10 to 15 years) than is supply equipment such as power stations (e.g. 40 to 50 years). So, far from becoming more electricity intensive as some projections would have it, the developed world – including the UK - will become less electricity intensive per capita, while enjoying the same energy services, and the world will converge at an annual average power per capita well below the present OECD levels.

5) The author talks of 'the growth of non-renewable low-carbon sources, namely "clean" coal, "clean" gas, and nuclear power'.

Could the author comment on: This is a logical impossibility. Growth in the use of any such finite resource can only result in collapse, as was shown in 'The Limits to Growth' study of 1973 and later updates. (http://en.wikipedia.org/wiki/The_Limits_to_Growth and http://www.amazon.co.uk/The-Limits-Growth-30-year-Update/dp/1844071448/ref=sr_1_1?ie=UTF8&qid=1344854336&sr=8-1 ). One way is from depletion to not a monetary limit (e.g. USD/tonne) but an energy limit (e.g. Joules/tonne). Collapse occurs when the energy cliff is reached, ending at the point of futility, where energy costs more energy to extract than it yields. The other way that the growth in the use of non-renewable sources leads to collapse is pollution. Most people accept that climate change is real and due to CO2 emissions far beyond the absorbtion capability of the planet. Moreover, although it was apparent even after Chernobyl, particularly since Fukushima many more have come to realise that radioactive discharges shorten peoples lives and render their homelands uninhabitable.

6) The author opines that: 'If solar is to play a large role in the future energy system, we need an energy storage solution; very-large-scale solar would either need to be combined with electricity stores, or it would need to serve a large flexible demand for energy that effectively stores useful energy in the form of chemicals, heat, or cold'.

Could the author comment on: This is a serious mis-reading of the problem. Above we saw how the electricity intensity per capita in the OECD will decline as large parts of the many thermodynamic potentials are realised by engineers. It then becomes clear that the most critical energy service is transport, not only of manufactured goods (as above) but vitally of food. The UK imports some 40 to 50% of it's food, so without fuel for the aircraft, ships, trains and trucks that bring it from abroad and for the tractors, harvesters etc that have raised agricultural labour productivity to such high levels, and for the petroleum-derived fertilisers, we will starve. Even the USA, which imports a much lower proportion of it's food, is wholly dependent on the trailer trucks to bring it from the farms to the urban populations. It is said to be three weeks from starvation, so a similar period probably applies to the UK.

So the storage problem is primarily of fluid fuels - mostly liquid – for transport. This accounts for about 30% of final energy in the UK. The hydrocarbons that we use today are of very high energy density, both gravimetric and volumetric, and these attributes are essential for all the above heavy duty vehicles. For example, the Breuget Range Equation for aircraft payload and range includes the gravimetric energy density of the fuel. However for aircraft, the volumetric energy density is less critical. (http://web.mit.edu/16.unified/www/FALL/Unified_Concepts/BreguetNoteseps.pdf pp 3, 5). The utility of ships, trains and trucks is affected by both gravimetric and volumetric energy densities. Moreover, such fuels are capable of transfer at very high power rates. Filling a car or truck involves power flows measured in MW, yet imposes no such load on the electricity grid.

The need for obtaining such fuels from renewable sources has been appreciated in some countries for many years. The most notable example is in Germany, where a research programme at the ZSW (Centre for Solar Energy and Hydrogen Research) in Stuttgart has been funded by the province of Baden-Wuttenburg for over 20 years, lead by Dr Michael Specht. This has borne fruit as a process for synthesising methane, using the Sabatier reaction. This has been shown in use as a fuel for cars (and thus of suitable trucks etc) and is easily converted to methanol and then to gasoline (petrol) and diesel with known chemical engineering. The inputs are renewable electricity to produce hydrogen and CO2, that may come from the air. These electrolysis and synthesis processes have losses manifest as low temperature heat, but as we saw above, we also have a huge demand for such heat, so cascading is in order. After an in-house pre-pilot plant had been built, a pilot plant of some 30 kW was co-

developed with Solar Fuel, also of Stuttgart. (http://www.youtube.com/watch?v=LqeFSxN2wAk ). A first industrial scale plant of 6.3 MW throughput is now being built at Werlte, in North West Germany, by partners including Siemens, who are providing 4 x 3.6 MWe wind turbines, located offshore in the North Sea, and Audi AG (of the VW Group), who presumably have realised that without fuel, cars will not sell.
(http://www.volkswagenag.com/content/vwcorp/info_center/en/themes/2011/05/Audi_balanced_mobility___The_route_to_CO2-neutral_mobility.html ). This plant will be on-stream next year (2013).

This development has been set in the larger context by Dr Michael Sterner in his doctoral thesis of 2009, written in English, at the University of Kassel. (http://www.uni-kassel.de/hrz/db4/extern/dbupress/publik/abstract.php?978-3-89958-798-2 ). In this he coined the term 'Renewable Power Methane' (RPM) for such fuel and showed that, if stored in the German natural gas grid and the caverns already used for storage, this would meet the German demand for electricity for several months.
(http://www.gridgas.co.uk/documents/Wind2SNG_ZSW_IWES_SolarFuel_FVEE.pdf and http://www.fraunhofer.de/en/press/research-news/2010/04/green-electricity-storage-gas.html). Again there would be conversion losses, both when 'charging' as above, and when 'discharging' the store, by thermodynamic conversion of methane to electricity in the existing gas-fired power plants. Yet as we saw above, there is a huge demand for low temperature heat, which can be met by cascading – in this case through large scale combined heat and power for district heating.

With a holistic view of the energy economy, having proper regard for the thermodynamic potentials, exergy matching, and thus the scope for cascading, it is no wonder that the Germans and others see things very differently from this author.

This paper should at least be revised to take account of other published work in this field, such as those cited above. However, with several factors crucial to the main argument omitted completely and others at variance by up to orders of magnitude, the data and analysis in this paper are likely only to misinform.