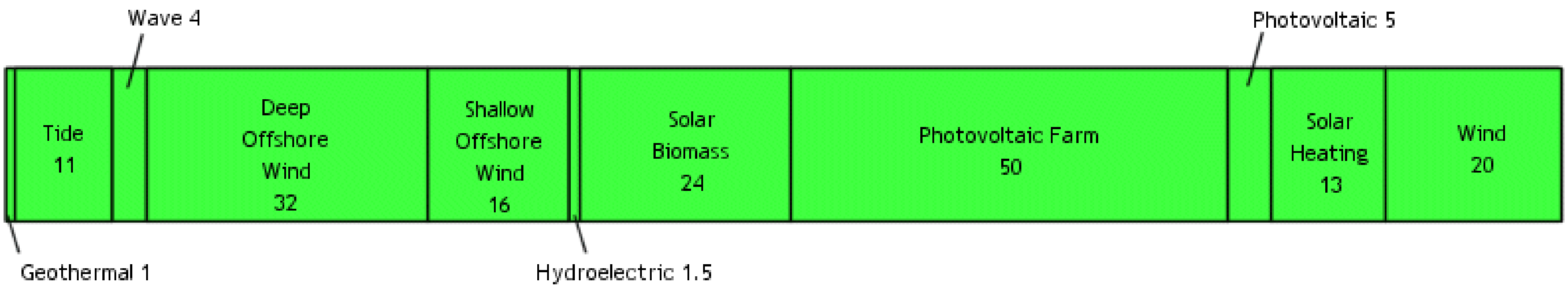
Could Britain live on Renewable Energy?

This worksheet covers:

- A summary of the maximum energy potentially available from renewable sources in the UK, introducing the concept of power density
- A summary of the current demands for energy in the UK
- A discussion of whether the UK could live on renewable energy
- Key UK reference data to use as quantitative benchmarks: average energy consumption per person per day, and average CO_2 emissions per person per day
- *Appendix*: summary of the assumptions behind the analysis of Mackay (2009), presented here.

Where could our energy come from?

There are many sources of energy that can be considered sustainable, or renewable. This means they rely on sources that are not going to run out within a reasonable timescale, such as the wind or the sun. It is useful to estimate the *maximum amount of energy we could conceivably get in* the UK from each renewable source – the outcome of such a calculation by Mackay (2009) is illustrated below. The energy values in this "stack" for renewable sources are in given in the convenient units of *kWh/day/person.* The grand total is ***180 kWh/day/person*** – we'll compare this with energy demand below.



(The assumptions behind these estimates are summarised in the Appendix; the resources on Energy Sources go into more details on these calculations).

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Power Density of different Energy Sources

Mackay's estimates take no account of economic or social constraints – only what might be technically accessible. A key quantity for a given source is the **power density:** the typical power output of an installation per unit area of land (or sea) that it occupies. (Note that wave power is given as a power per unit *length* of coastline)

The table below summarises the power densities of different renewable technologies.

Source	Typical power density
Geothermal	Not available
Tidal	Severn barrage: 8-30Wm^{-2}; tidal stream farm: 6Wm^{-2}; tidal lagoon: 4.5Wm^{-2}
Deep Offshore Wind	3 Wm^{-2}
Shallow Offshore Wind	3 Wm^{-2}
Onshore Wind	2 Wm^{-2} (for average wind speed of 6 ms^{-1})
Hydroelectric	0.24 Wm^{-2} (Highlands); 0.02 Wm^{-2} (Lowlands)
Solar Biomass	0.5 Wm^{-2}
Solar Photovoltaic (farm)	10 Wm^{-2}
Solar Photovoltaic (roof)	22 Wm^{-2}
Solar Heating	55 Wm^{-2}
Wave	40 kWm^{-1} (power/unit *length* of coastline)

How do these power densities compare with conventional sources?

To put these power densities in context: a 1000MW nuclear power station typically occupies 1 square kilometre. This gives a power density of 1000Wm^{-2}, i.e. 50-5000 times greater than the renewable energy sources.

Conclusion: renewable energy can take a lot of space!

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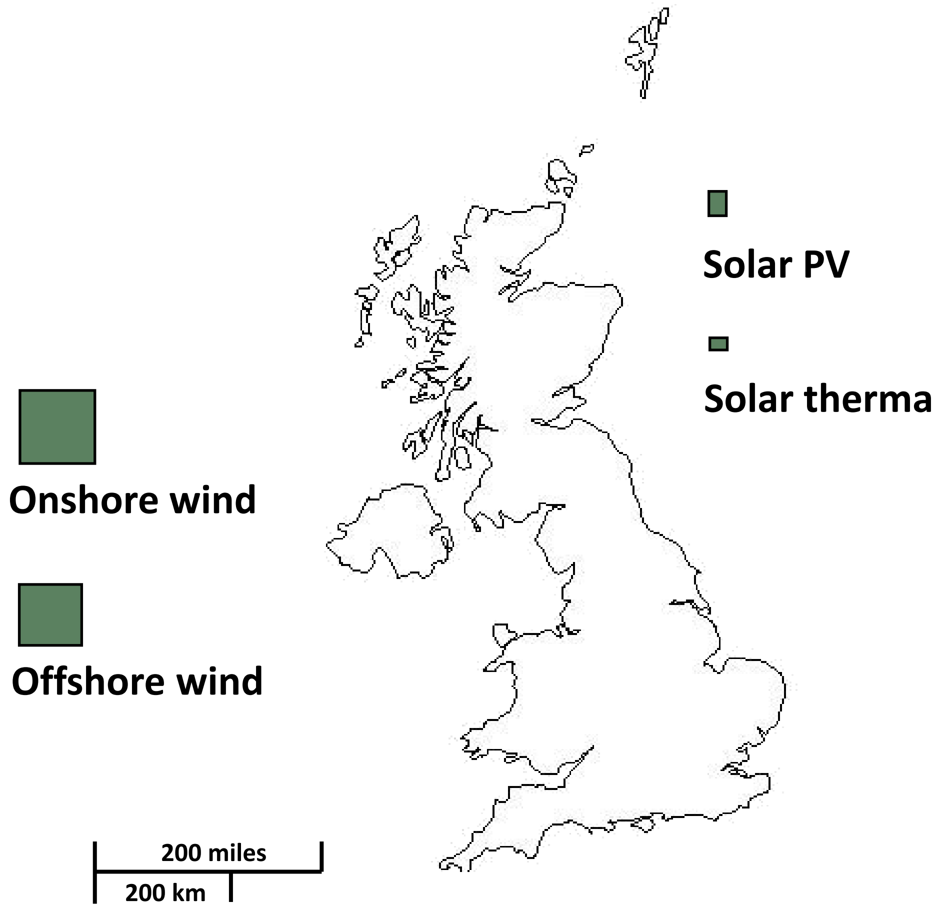
Estimated area needed to provide 10% of UK primary energy

Another way to illustrate the area of installation needed for renewable sources is to estimate the area that would be needed for each source to provide 10% of the UK's current primary energy demand (about 12.5 kWh/day/person – see below).

The map shows the result for a number of renewable sources – it is easy to see that very large areas can be needed to produce significant power contributions from renewable sources (due to their low power densities).



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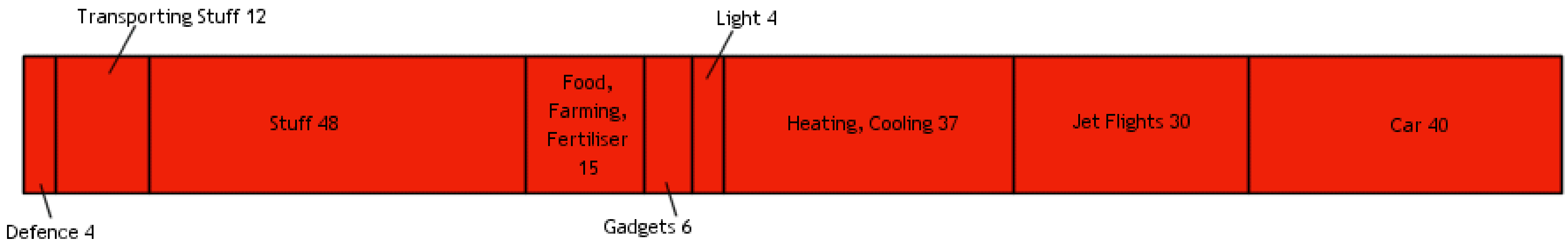
What do we use our energy for?

Demands for energy range from burning fossil fuels in a car to drive around, to using electricity to power our televisions. The figure shows estimates of the *average amount of energy consumed* under different demands, on the same scale as the sources stack (MacKay, 2009). The grand total is **195 kWh/person/day.**



(The assumptions behind these estimates are summarised in the Appendix; the resources on Energy Demands go into more details on these calculations, enabling you to make an estimate for your own energy usage).

Average UK demand for primary energy

Energy consumption is highly individual, the estimates above is for a moderately affluent household. Mackay also quotes the UK (and European) average figure of **125 kWh/person/day**, with heating and transport again being the dominant usage. In these Resources we use this figure as our reference for “current UK primary energy”.

Comparison with other countries is also revealing (see Mackay for details):

- the figure or the USA is double that for the UK: 250 kWh/person/day
- for China and India it is around 20 kWh/person/day (but growing rapidly)
- energy consumption correlates strongly with Gross Domestic Product (GDP)

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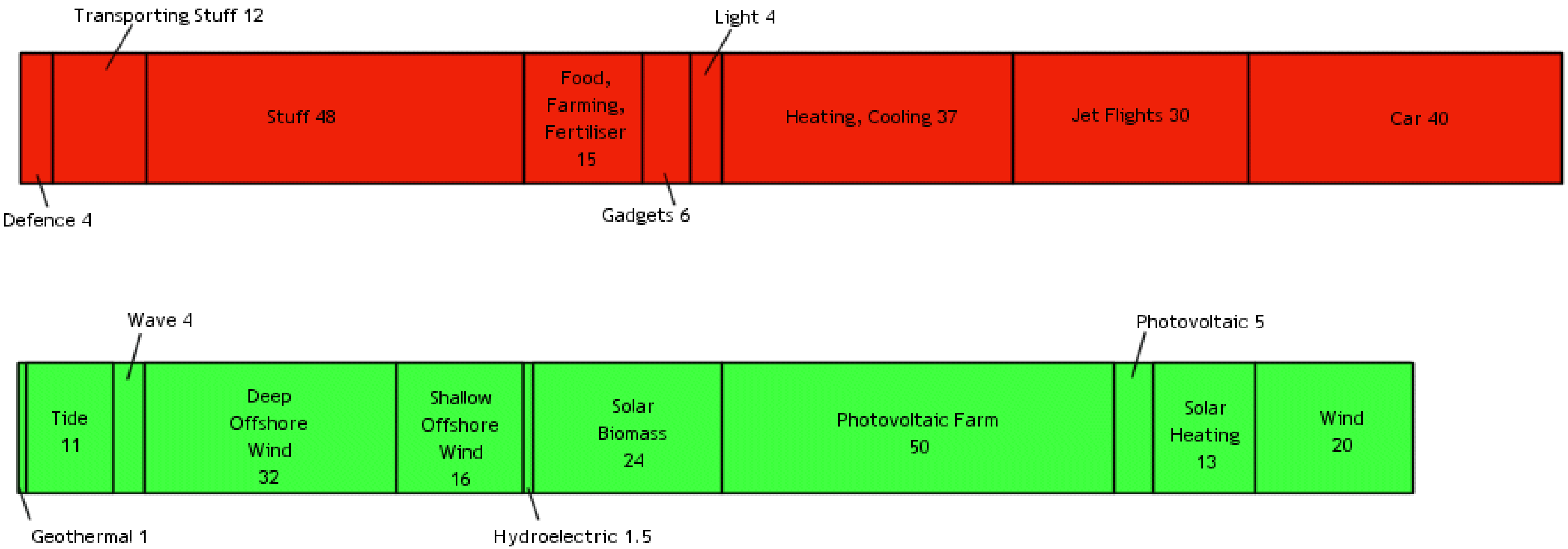

Putting the stacks side-by-side initially suggests that in theory there could be enough renewable energy to cover our needs (180kWh/day/person supply, against a demand of 195kWh/day/person – more than enough if we use the lower figure of 125 kWh/day/person).

However, we must note that:

(1) social and economic constraints cannot be ignored – Mackay and others suggest that realistically we might expect renewables to add up to about 12-27kWh/day/person (this is still over 10 times more than the 1.05 kWh/day/person we generated in 2006).

(2) the supply side is nearly all electrical energy, but cars and planes use fossil fuels directly, not electricity. Electric cars may develop rapidly in the next decade, but planes must burn hydrocarbon fuel (due to its very high energy content per unit weight).

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So renewables can only be part of the solution – we will need other non-fossil fuel energy sources, e.g. nuclear power, or importing electricity from countries with huge renewable energy potential (e.g. solar power from north Africa). But we also need to reduce our energy use in order to move away from fossil fuels.

The energy used for transportation can be reduced by using more public transport and moving towards electric cars. And we can change our attitudes towards how far we drive on a daily basis (a huge number of journeys are under a mile or so), and where we holiday (do we really need to fly everywhere to get some sun?).

The energy used in heating and cooling can also be reduced by being more efficient about how we heat the places where we live and work (for example using heat pumps, and installing insulation). And again, attitudes could change towards how we stay comfortable – does the thermostat really have to be set that high, or could we just put on another jumper?

Conclusion

The main message from Mackay is that ***the debate on energy and carbon emission must be quantitative, and any proposed solutions must add up.*** Renewable energy and nuclear will be part of the solution, but only if we start saying yes to their development (instead of dismissing them out of hand on social and economic constraints), and at the same time reducing our demand for energy.

Key Reference Data for Energy and CO_2 emissions

The accompanying resources go into more details of renewable energy sources, and energy demands, to help you make your own estimates. To put each energy source or use in context, we use Mackay's estimate of average energy consumption in the UK: **125 kWh per person per day.**

To extend the discussion to carbon footprinting, we will also use the average UK person's CO_2(eq) footprint :
11 tons of CO_2(eq) per year; or **30 kg per day**.

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Source

- MacKay DJC, 2009: Sustainable Energy – without the hot air, UIT Cambridge.

Also available free online from www.withouthotair.com

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Appendix:

Summary of assumptions behind Mackay's analysis of UK renewable energy potential, and energy demands

Energy Sources

The table below summarises the scale of installation assumed by Mackay in building the energy sources stack, and the corresponding power densities (including typical efficiencies of current technology). Note that all of these sources output *electrical energy* (with the exception of *solar heating*).

Source	Scale of installation	Typical power density
Geothermal	All viable "hot dry rock" (e.g. in Cornwall)	Not available
Tidal	Severn barrage: 500km^2; tidal stream farm: all viable sites >2 knots; tidal lagoon: 800km^2	Severn barrage: 8-30Wm^{-2}; tidal stream farm: 6Wm^{-2}; tidal lagoon: 4.5Wm^{-2}
Deep Offshore Wind	33% of UK deep waters (33% x 80,000km^2)	3 Wm^{-2}
Shallow Offshore Wind	33% of UK shallow waters (33% x 40,000km^2)	3 Wm^{-2}
Onshore Wind	10% of UK land area (400m^2 per person)	2 Wm^{-2} (for average wind speed of 6 ms^{-1})
Hydroelectric	20% of all Highlands rain catchment area; 10% of all Lowlands rain catchment area	0.24 Wm^{-2} (Highlands); 0.02 Wm^{-2} (Lowlands)
Solar Biomass	75% of UK land area (3000m^2 per person)	0.5 Wm^{-2}
Solar Photovoltaic Farm	5% of UK land area (200m^2 per person)	10 Wm^{-2}
Solar Photovoltaic	All south-facing roofs (10m^2 per person)	22 Wm^{-2}
Solar Heating	All south-facing roofs (10m^2 per person)	55 Wm^{-2}
Wave	50% of Atlantic coastline (50% of 1000km)	40 kWm^{-1} (power/unit *length* of coastline)

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Energy Demands

The table below summarises the basis of the analyses by Mackay in building the energy demands stack. The resources under Energy Demands go into more details.

The profile of energy consumption is of course highly individual – for example, car miles maybe much more or less than 50 km per day, and people have very different amounts of stuff and gadgets. It is easy enough to estimate your own energy breakdown – the resources on *Energy Demands* show you how.

Demand	Assumptions
Cars	Average distance of 50 km driven per day (the average for car owners, not whole population)
Flights	20,000 km (e.g. London to Cape Town round trip), once a year, plane 80% full
Heating and Cooling	Roughly 1/3 of total is for heating hot water and food (kettles, cookers, washing machines), and 2/3 is for heating hot air (household heaters); small cooling contribution (fridge-freezers and air conditioning)
Light	Electricity used by 10 incandescent bulbs and 10 low-energy lights per household (5 hours/day)
Gadgets	Electricity consumption of computers, entertainment systems, phones, vacuum cleaners etc.
Food and Farming	Calorific energy in animal feed (to produce meat, eggs and dairy products), plus a contribution for fertilizers, farm machinery and refrigeration
Stuff	Mostly the “embodied energy” in the materials used to make vehicles, white goods, computers, paper, packaging, roads, buildings
Transporting Stuff	Mostly transport of imported stuff by air, sea, road or pipe, and food storage before sale
Defence	6% of defence budget spent on energy (same as overall GDP)