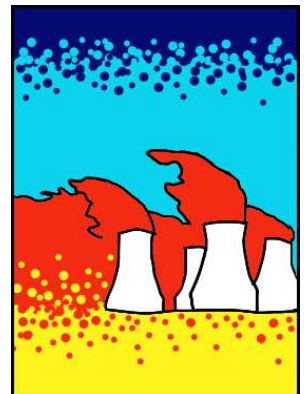


Part IV

Useful data



I Quick reference

SI Units

The watt. This SI unit is named after James Watt. As for all SI units whose names are derived from the proper name of a person, the first letter of its symbol is uppercase (W). But when an SI unit is spelled out, it should always be written in lowercase (watt), with the exception of the “degree Celsius.”

from wikipedia

SI stands for *Système Internationale*. SI units are the ones that all engineers should use, to avoid losing spacecraft.

SI units			prefix	kilo	mega	giga	tera	peta	exa
energy	one joule	1 J	symbol	k	M	G	T	P	E
power	one watt	1 W	factor	10^3	10^6	10^9	10^{12}	10^{15}	10^{18}
force	one newton	1 N							
length	one metre	1 m	prefix	centi	milli	micro	nano	pico	femto
time	one second	1 s	symbol	c	m	μ	n	p	f
temperature	one kelvin	1 K	factor	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}

Table 1.1. SI units and prefixes

My preferred units for energy, power, and transport efficiencies

My preferred units, expressed in SI			
energy	one kilowatt-hour	1 kWh	3 600 000 J
power	one kilowatt-hour per day	1 kWh/d	$(1000/24)W \simeq 40 W$
force	one kilowatt-hour per 100 km	1 kWh/100 km	36 N
time	one hour	1 h	3600 s
	one day	1 d	$24 \times 3600 s \simeq 10^5 s$
	one year	1 y	$365.25 \times 24 \times 3600 s \simeq \pi \times 10^7 s$
force per mass	kilowatt-hour per ton-kilometre	1 kWh/t-km	$3.6 m/s^2 (\simeq 0.37g)$

Additional units and symbols

Thing measured	unit name	symbol	value
humans	person	p	
mass	ton	t	1 t = 1000 kg
	gigaton	Gt	1 Gt = $10^9 \times 1000 \text{ kg} = 1 \text{ Pg}$
transport	person-kilometre	p-km	
transport	ton-kilometre	t-km	
volume	litre	l	1 l = 0.001 m ³
area	square kilometre	sq km, km ²	1 sq km = 10 ⁶ m ²
	hectare	ha	1 ha = 10 ⁴ m ²
	Wales		1 Wales = 21 000 km ²
	London (Greater London)		1 London = 1580 km ²
energy	Dinorwig		1 Dinorwig = 9 GWh

Billions, millions, and other people's prefixes

Throughout this book “a billion” (1 bn) means a standard American billion, that is, 10^9 , or a thousand million. A trillion is 10^{12} . The standard prefix meaning “billion” (10^9) is “giga.”

In continental Europe, the abbreviations Mio and Mrd denote a million and billion respectively. Mrd is short for milliard, which means 10^9 .

The abbreviation m is often used to mean million, but this abbreviation is incompatible with the SI – think of mg (milligram) for example. So I don't use m to mean million. Where some people use m, I replace it by M. For example, I use Mtoe for million tons of oil equivalent, and Mt CO₂ for million tons of CO₂.

Annoying units

There's a whole bunch of commonly used units that are annoying for various reasons. I've figured out what some of them mean. I list them here, to help you translate the media stories you read.

Homes

The “home” is commonly used when describing the power of renewable facilities. For example, “The £300 million Whitelee wind farm's 140 turbines will generate 322 MW – enough to power 200 000 homes.” The “home” is defined by the British Wind Energy Association to be a power of **4700 kWh per year** [www.bwea.com/ukwed/operational.asp]. That's 0.54 kW, or **13 kWh per day**. (A few other organizations use 4000 kWh/y per household.)

The “home” annoys me because I worry that people confuse it with *the total power consumption of the occupants of a home* – but the latter is actually

about 24 times bigger. The “home” covers the average domestic *electricity* consumption of a household, only. Not the household’s home heating. Nor their workplace. Nor their transport. Nor all the energy-consuming things that society does for them.

Incidentally, when they talk of the CO₂ emissions of a “home,” the official exchange rate appears to be 4 tons CO₂ per home per year.

Power stations

Energy saving ideas are sometimes described in terms of power stations. For example according to a BBC report on putting new everlasting LED lightbulbs in traffic lights, “The power savings would be huge – keeping the UK’s traffic lights running requires the equivalent of two medium-sized power stations.” news.bbc.co.uk/1/low/sci/tech/specials/sheffield_99/449368.stm

What is a medium-sized power station? 10 MW? 50 MW? 100 MW? 500 MW? I don’t have a clue. A google search indicates that some people think it’s 30 MW, some 250 MW, some 500 MW (the most common choice), and some 800 MW. What a useless unit!

Surely it would be clearer for the article about traffic lights to express what it’s saying as a percentage? “Keeping the UK’s traffic lights running requires 11 MW of electricity, which is 0.03% of the UK’s electricity.” This would reveal how “huge” the power savings are.

Figure I.2 shows the powers of the UK’s 19 coal power stations.

Cars taken off the road

Some advertisements describe reductions in CO₂ pollution in terms of the “equivalent number of cars taken off the road.” For example, Richard Branson says that if Virgin Trains’ Voyager fleet switched to 20% biodiesel – incidentally, don’t you feel it’s outrageous to call a train a “green biodiesel-powered train” when it runs on 80% fossil fuels and just 20% biodiesel? – sorry, I got distracted. Richard Branson says that *if* Virgin Trains’ Voyager fleet switched to 20% biodiesel – I emphasize the “*if*” because people like Beadie are always getting media publicity for announcing that they are *thinking of* doing good things, but some of these fanfared initiatives are later quietly cancelled, such as the idea of towing aircraft around airports to make them greener – sorry, I got distracted again. Richard Branson says that *if* Virgin Trains’ Voyager fleet switched to 20% biodiesel, then there would be a reduction of 34 500 tons of CO₂ per year, which is equivalent to “23 000 cars taken off the road.” This statement reveals the exchange rate:

“one car taken off the road” \longleftrightarrow –1.5 tons per year of CO₂.

Calories

The calorie is annoying because the diet community call a kilocalorie a Calorie. 1 such food Calorie = 1000 calories.

2500 kcal = 3 kWh = 10 000 kJ = 10 MJ.

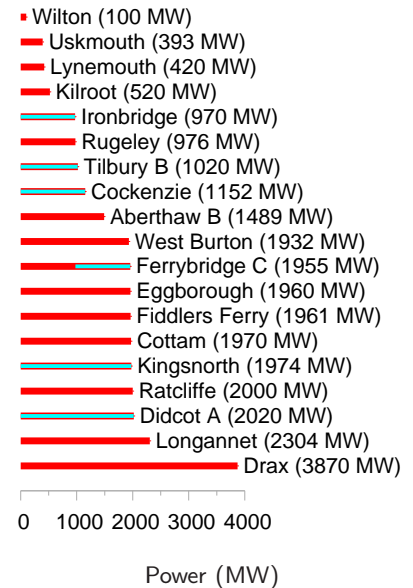


Figure I.2. Powers of Britain’s coal power stations. I’ve highlighted in blue 8 GW of generating capacity that will close by 2015. 2500 MW, shared across Britain, is the same as 1 kWh per day per person.

I — Quick reference

Barrels

An annoying unit loved by the oil community, along with the ton of oil. Why can't they stick to one unit? A barrel of oil is 6.1 GJ or 1700 kWh.

Barrels are doubly annoying because there are multiple definitions of barrels, all having different volumes.

Here's everything you need to know about barrels of oil. One barrel is 42 U.S. gallons, or 159 litres. One barrel of oil is 0.1364 tons of oil. One barrel of crude oil has an energy of 5.75 GJ. One barrel of oil weighs 136 kg. One ton of crude oil is 7.33 barrels and 42.1 GJ. The carbon-pollution rate of crude oil is 400 kg of CO₂ per barrel. www.chemlink.com.au/conversions.htm This means that when the price of oil is \$100 per barrel, oil energy costs 6¢ per kWh. If there were a carbon tax of \$250 per ton of CO₂ on fossil fuels, that tax would increase the price of a barrel of oil by \$100.

Gallons

The gallon would be a fine human-friendly unit, except the Yanks messed it up by defining the gallon differently from everyone else, as they did the pint and the quart. The US volumes are all roughly five-sixths of the correct volumes.

1 US gal = 3.7851 = 0.83 imperial gal. 1 imperial gal = 4.5451.

Tons

Tons are annoying because there are short tons, long tons and metric tons. They are close enough that I don't bother distinguishing between them. 1 short ton (2000 lb) = 907 kg; 1 long ton (2240 lb) = 1016 kg; 1 metric ton (or tonne) = 1000 kg.

BTU and quads

British thermal units are annoying because they are neither part of the *Système Internationale*, nor are they of a useful size. Like the useless joule, they are too small, so you have to roll out silly prefixes like "quadrillion" (10¹⁵) to make practical use of them.

1 kJ is 0.947 BTU. 1 kWh is 3409 BTU.

A "quad" is 1 quadrillion BTU = 293 TWh.

Funny units

Cups of tea

Is this a way to make solar panels sound good? "Once all the 7000 photovoltaic panels are in place, it is expected that the solar panels will create 180 000 units of renewable electricity each year – enough energy to make **nine million cups of tea.**" This announcement thus equates 1 kWh to 50 cups of tea.

As a unit of volume, 1 US cup (half a US pint) is officially 0.24l; but a cup of tea or coffee is usually about 0.18l. To raise 50 cups of water, at 0.18l per cup, from 15 °C to 100 °C requires 1 kWh.

So “nine million cups of tea per year” is another way of saying “20 kW.”

Double-decker buses, Albert Halls and Wembley stadiums

“If everyone in the UK that could, installed cavity wall insulation, we could cut carbon dioxide emissions by a huge 7 million tons. That’s enough carbon dioxide to fill nearly 40 million double-decker buses or fill the new Wembley stadium 900 times!”

From which we learn the helpful fact that one Wembley is 44 000 double-decker buses. Actually, Wembley’s bowl has a volume of 1 140 000 m³.

“If every household installed just one energy saving light bulb, there would be enough carbon dioxide saved to fill the Royal Albert Hall 1,980 times!” (An Albert Hall is 100 000 m³.)

Expressing amounts of CO₂ by volume rather than mass is a great way to make them sound big. Should “1 kg of CO₂ per day” sound too small, just say “200 000 litres of CO₂ per year”!

More volumes

A container is 2.4 m wide by 2.6 m high by (6.1 or 12.2) metres long (for the TEU and FEU respectively).

One TEU is the size of a small 20-foot container – an interior volume of about 33 m³. Most containers you see today are 40-foot containers with a size of 2 TEU. A 40-foot container weighs 4 tons and can carry 26 tons of stuff; its volume is 67.5 m³.

A swimming pool has a volume of about 3000 m³.

One double-decker bus has a volume of 100 m³.

One hot air balloon is 2500 m³.

The great pyramid at Giza has a volume of 2 500 000 cubic metres.

Areas

The area of the earth’s surface is 500 × 10⁶ km²; the land area is 150 × 10⁶ km².

My typical British 3-bedroom house has a floor area of 88 m². In the USA, the average size of a single-family house is 2330 square feet (216 m²).

Powers

If we add the suffix “e” to a power, this means that we’re explicitly talking about electrical power. So, for example, a power station’s output might be 1 GW(e), while it uses chemical power at a rate of 2.5 GW. Similarly the

mass of CO ₂	↔	volume
2 kg CO ₂	↔	1 m ³
1 kg CO ₂	↔	500 litres
44 g CO ₂	↔	22 litres
2 g CO ₂	↔	1 litre

Table I.3. Volume-to-mass conversion.



Figure I.4. A twenty-foot container (1 TEU).

hectare	=	10 ⁴ m ²
acre	=	4050 m ²
square mile	=	2.6 km ²
square foot	=	0.093 m ²
square yard	=	0.84 m ²

Table I.5. Areas.

Land use	area per person (m ²)	percentage
– domestic buildings	30	1.1
– domestic gardens	114	4.3
– other buildings	18	0.66
– roads	60	2.2
– railways	3.6	0.13
– paths	2.9	0.11
– greenspace	2335	87.5
– water	69	2.6
– other land uses	37	1.4
Total	2670	100

Table I.6. Land areas, in England, devoted to different uses. Source: Generalized Land Use Database Statistics for England 2005. [3b7zdf]

1000 BTU per hour	=	0.3 kW	=	7 kWh/d
1 horse power (1 hp or 1 cv or 1 ps)	=	0.75 kW	=	18 kWh/d
		1 kW	=	24 kWh/d
1 therm	=	29.31 kWh		
1000 Btu	=	0.2931 kWh		
1 MJ	=	0.2778 kWh		
1 GJ	=	277.8 kWh		
1 toe (ton of oil equivalent)	=	11 630 kWh		
1 kcal	=	1.163×10^{-3} kWh		
1 kWh	=	0.03412 therms	=	3412 Btu
			=	3.6 MJ
			=	86×10^{-6} toe
			=	859.7 kcal

Box I.7. How other energy and power units relate to the kilowatt-hour and the kilowatt-hour per day.

suffix “th” may be added to indicate that a quantity of energy is thermal energy. The same suffixes can be added to amounts of energy. “My house uses 2 kWh(e) of electricity per day.”

If we add a suffix “p” to a power, this indicates that it’s a “peak” power, or capacity. For example, 10 m² of panels might have a power of 1 kWp.

$$1 \text{ kWh/d} = \frac{1}{24} \text{ kW.}$$

$$1 \text{ toe/y} = 1.33 \text{ kW.}$$

Petrol comes out of a petrol pump at about half a litre per second. So that’s 5 kWh per second, or 18 MW.

The power of a Formula One racing car is 560 kW.

UK electricity consumption is 17 kWh per day per person, or 42.5 GW per UK.

“One ton” of air-conditioning = 3.5 kW.

World power consumption

World power consumption is 15 TW. World electricity consumption is 2 TW.

Useful conversion factors

To change TWh per year to GW, divide by 9.

1 kWh/d per person is the same as 2.5 GW per UK, or 22 TWh/y per UK

To change mpg (miles per UK gallon) to km per litre, divide by 3.

At room temperature, $1 kT = \frac{1}{40} eV$

At room temperature, $1 kT$ per molecule = 2.5 kJ/mol.

Meter reading

How to convert your gas-meter reading into kilowatt-hours:

- If the meter reads **100s of cubic feet**, take the number of units used, and multiply by **32.32** to get the number of kWh.
- If the meter reads **cubic metres**, take the number of units used, and multiply by **11.42** to get the number of kWh.

Calorific values of fuels

Crude oil: 37 MJ/l; 10.3 kWh/l.

Natural gas: 38 MJ/m³. (Methane has a density of 1.819 kg/m³.)

1 ton of coal: 29.3 GJ; 8000 kWh.

Fusion energy of ordinary water: 1800 kWh per litre.

See also table 26.14, p199, and table D.3, p284.

Heat capacities

The heat capacity of air is 1 kJ/kg/°C, or 29 J/mol/°C. The density of air is 1.2 kg/m³. So the heat capacity of air per unit volume is 1.2 kJ/m³/°C.

Latent heat of vaporization of water: 2257.92 kJ/kg. Water vapour's heat capacity: 1.87 kJ/kg/°C. Water's heat capacity is 4.2 kJ/l/°C.

Steam's density is 0.590 kg/m³.

Pressure

Atmospheric pressure: 1 bar \simeq 10⁵ Pa (pascal). Pressure under 1000 m of water: 100 bar. Pressure under 3000 m of water: 300 bar.

	kWh/t-km
inland water	0.083
rail	0.083
truck	0.75
air	2.8
oil pipeline	0.056
gas pipeline	0.47
int'l water container	0.056
int'l water bulk	0.056
int'l water tanker	0.028

Table 1.8. Energy intensity of transport modes in the USA. Source: Weber and Matthews (2008).

Money

I assumed the following exchange rates when discussing money: €1 = \$1.26; £1 = \$1.85 ; \$1 = \$1.12 Canadian. These exchange rates were correct in mid-2006.

Greenhouse gas conversion factors

France	83
Sweden	87
Canada	220
Austria	250
Belgium	335
European Union	353
Finland	399
Spain	408
Japan	483
Portugal	525
United Kingdom	580
Luxembourg	590
Germany	601
USA	613
Netherlands	652
Italy	667
Ireland	784
Greece	864
Denmark	881

Figure I.9. Carbon intensity of electricity production (g CO₂ per kWh of electricity).

Fuel type	emissions (g CO ₂ per kWh of chemical energy)
natural gas	190
refinery gas	200
ethane	200
LPG	210
jet kerosene	240
petrol	240
gas/diesel oil	250
heavy fuel oil	260
naptha	260
coking coal	300
coal	300
petroleum coke	340

Figure I.10. Emissions associated with fuel combustion. Source: DEFRA's Environmental Reporting Guidelines for Company Reporting on Greenhouse Gas Emissions.

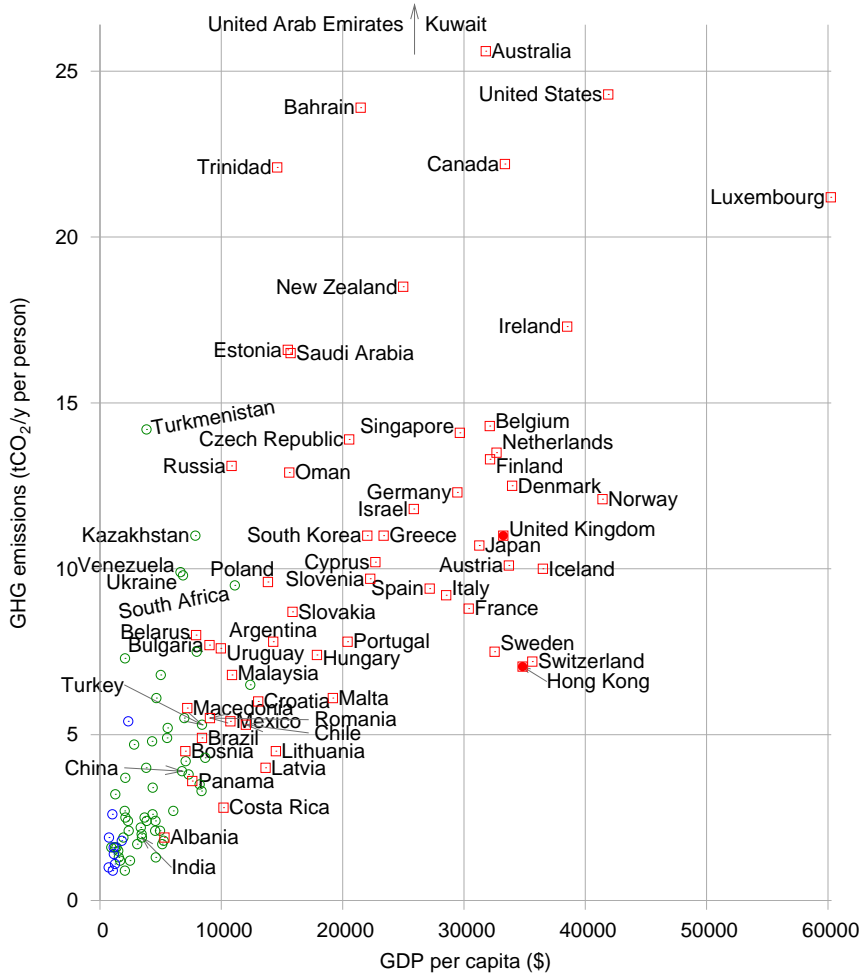


Figure I.11. Greenhouse-gas emissions per capita, versus GDP per capita, in purchasing-power-parity US dollars. Squares show countries having “high human development;” circles, “medium” or “low.” See also figures 30.1 (p231) and 18.4 (p105). Source: UNDP Human Development Report, 2007. [3av4s9]

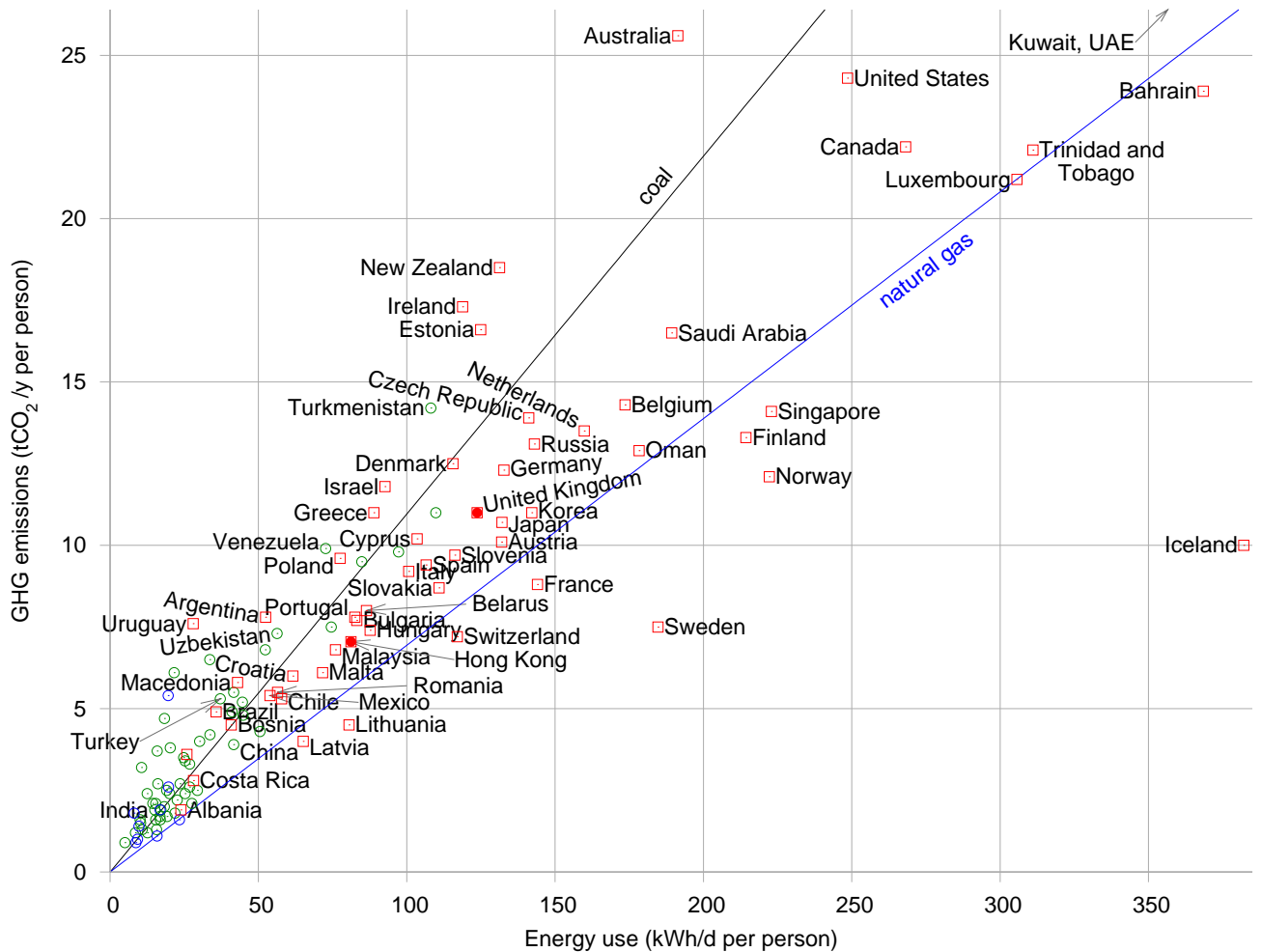


Figure I.12. Greenhouse-gas emissions per capita, versus power consumption per capita. The lines show the emission-intensities of coal and natural gas. Squares show countries having “high human development;” circles, “medium” or “low.” See also figures 30.1 (p231) and 18.4 (p105). Source: UNDP Human Development Report, 2007.

J Populations and areas

Population densities

Figure J.1 shows the areas of various regions versus their populations. Diagonal lines on this diagram are lines of constant population density. Bangladesh, on the rightmost-but-one diagonal, has a population density of 1000 per square kilometre; India, England, the Netherlands, and Japan have population densities one third that: about 350 per km². Many European countries have about 100 per km². At the other extreme, Canada, Australia, and Libya have population densities of about 3 people per km². The central diagonal line marks the population density of the world: 43 people per square kilometre. America is an average country from this point of view: the 48 contiguous states of the USA have the same population density as the world. Regions that are notably rich in area, and whose population density is below the average, include Russia, Canada, Latin America, Sudan, Algeria, and Saudi Arabia.

Of these large, area-rich countries, some that are close to Britain, and with whom Britain might therefore wish to be friendly, are Kazakhstan, Libya, Saudi Arabia, Algeria, and Sudan.

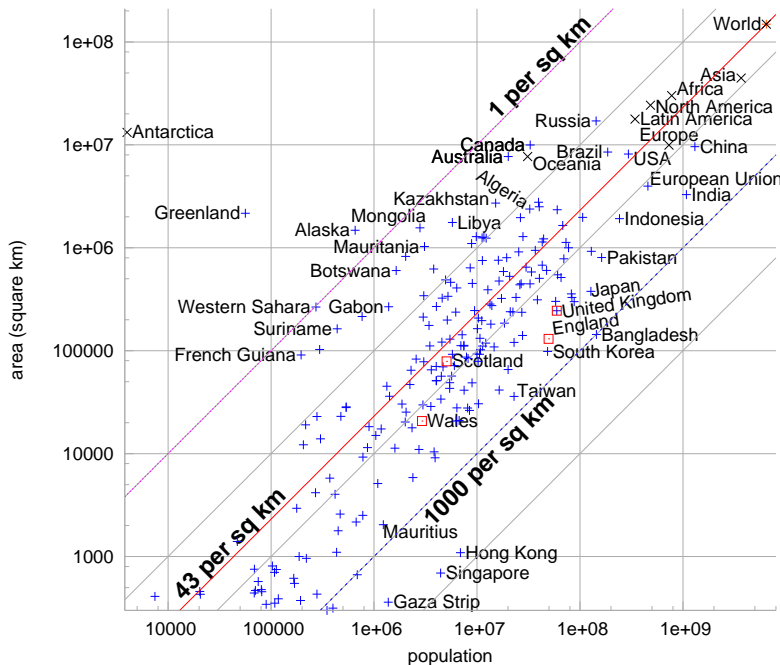


Figure J.1. Populations and areas of countries and regions of the world. Both scales are logarithmic. Each sloping line identifies a population density; countries with highest population density are towards the lower right, and lower population densities are towards the upper left. These data are provided in tabular form on p341.

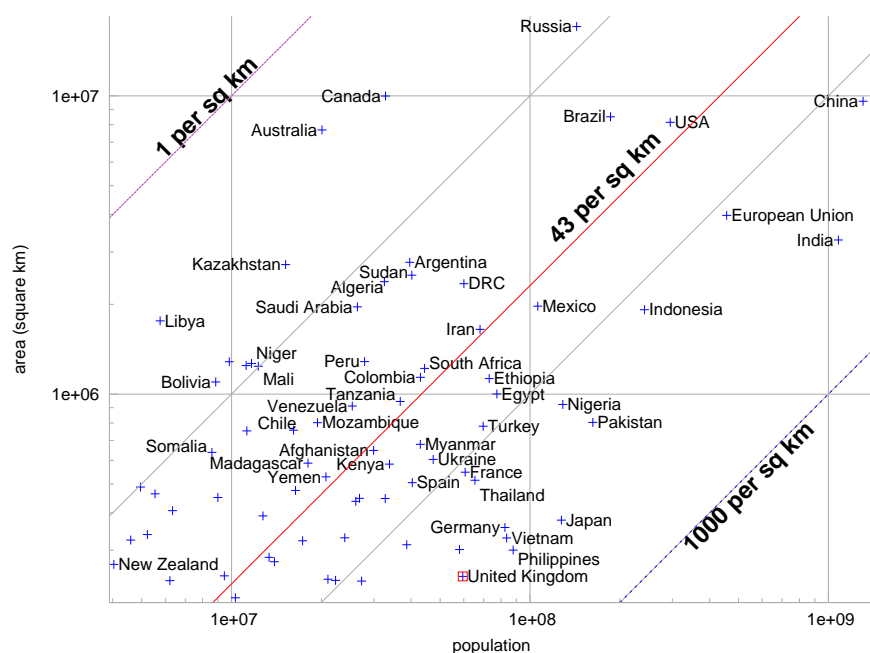


Figure J.2. Populations and areas of countries and regions of the world. Both scales are logarithmic. Sloping lines are lines of constant population density. This figure shows detail from figure J.1 (p338). These data are provided in tabular form on p341.

Region	Population	Land area (km ²)	People per km ²	Area each (m ²)
World	6 440 000 000	148 000 000	43	23 100
Asia	3 670 000 000	44 500 000	82	12 100
Africa	778 000 000	30 000 000	26	38 600
Europe	732 000 000	9 930 000	74	13 500
North America	483 000 000	24 200 000	20	50 200
Latin America	342 000 000	17 800 000	19	52 100
Oceania	31 000 000	7 680 000	4	247 000
Antarctica	4 000	13 200 000		

Table J.3. Population densities of the continents. These data are displayed graphically in figures J.1 and J.2. Data are from 2005.

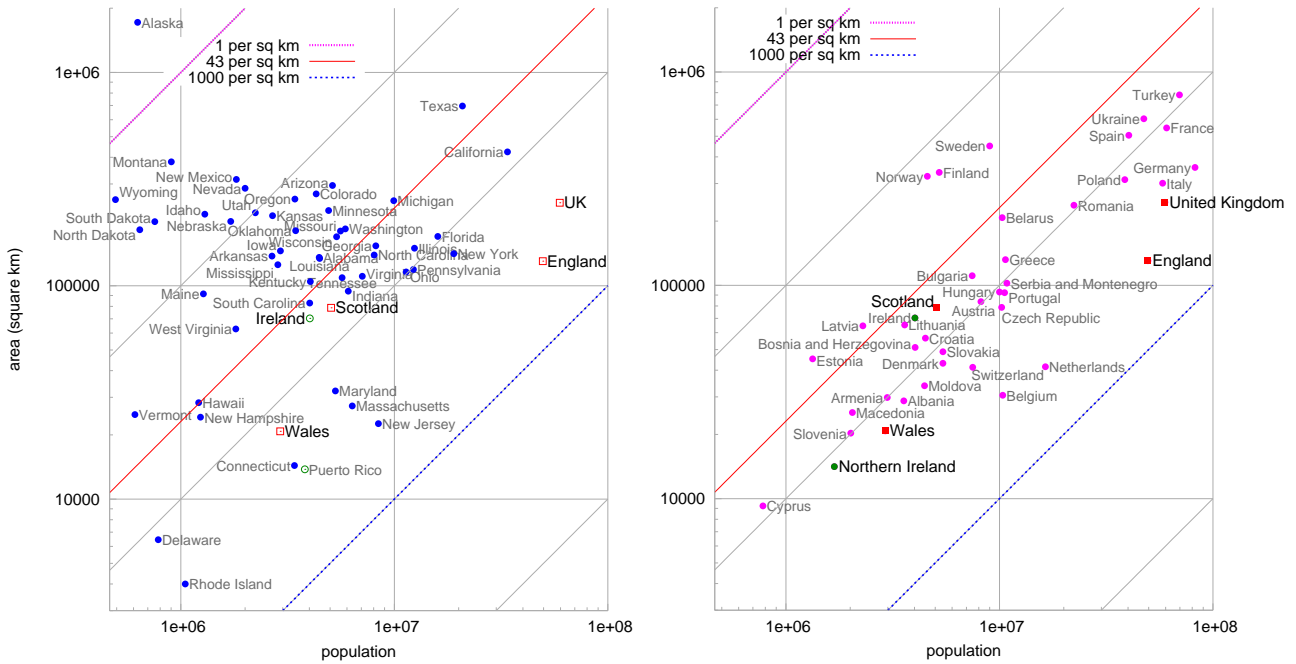


Figure J.4. Populations and areas of the States of America and regions around Europe.

Region	Population	Area (km ²)	People per km ²	Area per person (m ²)	Region	Population	Area (km ²)	People per km ²	Area per person (m ²)
Afghanistan	29 900 000	647 000	46	21 600	Lithuania	3 590 000	65 200	55	18 100
Africa	778 000 000	30 000 000	26	38 600	Madagascar	18 000 000	587 000	31	32 500
Alaska	655 000	1 480 000	0.44	2 260 000	Mali	12 200 000	1 240 000	10	100 000
Albania	3 560 000	28 700	123	8 060	Malta	398 000	316	1 260	792
Algeria	32 500 000	2 380 000	14	73 200	Mauritania	3 080 000	1 030 000	3	333 000
Angola	11 100 000	1 240 000	9	111 000	Mexico	106 000 000	1 970 000	54	18 500
Antarctica	4 000	13 200 000			Moldova	4 450 000	33 800	131	7 590
Argentina	39 500 000	2 760 000	14	69 900	Mongolia	2 790 000	1 560 000	1.8	560 000
Asia	3 670 000 000	44 500 000	82	12 100	Mozambique	19 400 000	801 000	24	41 300
Australia	20 000 000	7 680 000	2.6	382 000	Myanmar	42 900 000	678 000	63	15 800
Austria	8 180 000	83 800	98	10 200	Namibia	2 030 000	825 000	2.5	406 000
Bangladesh	144 000 000	144 000	1 000	997	Netherlands	16 400 000	41 500	395	2 530
Belarus	10 300 000	207 000	50	20 100	New Zealand	4 030 000	268 000	15	66 500
Belgium	10 000 000	31 000	340	2 945	Niger	11 600 000	1 260 000	9	108 000
Bolivia	8 850 000	1 090 000	8	124 000	Nigeria	128 000 000	923 000	139	7 170
Bosnia & Herzegovina	4 020 000	51 100	79	12 700	North America	483 000 000	24 200 000	20	50 200
Botswana	1 640 000	600 000	2.7	366 000	Norway	4 593 000	324 000	14	71 000
Brazil	186 000 000	8 510 000	22	45 700	Oceania	31 000 000	7 680 000	4	247 000
Bulgaria	7 450 000	110 000	67	14 800	Pakistan	162 000 000	803 000	202	4 940
CAR	3 790 000	622 000	6	163 000	Peru	27 900 000	1 280 000	22	46 000
Canada	32 800 000	9 980 000	3.3	304 000	Philippines	87 800 000	300 000	292	3 410
Chad	9 820 000	1 280 000	8	130 000	Poland	39 000 000	313 000	124	8 000
Chile	16 100 000	756 000	21	46 900	Portugal	10 500 000	92 300	114	8 740
China	1 300 000 000	9 590 000	136	7 340	Republic of Macedonia	2 040 000	25 300	81	12 300
Colombia	42 900 000	1 130 000	38	26 500	Romania	22 300 000	237 000	94	10 600
Croatia	4 490 000	56 500	80	12 500	Russia	143 000 000	17 000 000	8	119 000
Czech Republic	10 200 000	78 800	129	7 700	Saudi Arabia	26 400 000	1 960 000	13	74 200
DRC	60 000 000	2 340 000	26	39 000	Scotland	5 050 000	78 700	64	15 500
Denmark	5 430 000	43 000	126	7 930	Serbia & Montenegro	10 800 000	102 000	105	9 450
Egypt	77 500 000	1 000 000	77	12 900	Singapore	4 420 000	693	6 380	156
England	49 600 000	130 000	380	2 630	Slovakia	5 430 000	48 800	111	8 990
Estonia	1 330 000	45 200	29	33 900	Slovenia	2 010 000	20 200	99	10 000
Ethiopia	73 000 000	1 120 000	65	15 400	Somalia	8 590 000	637 000	13	74 200
Europe	732 000 000	9 930 000	74	13 500	South Africa	44 300 000	1 210 000	36	27 500
European Union	496 000 000	4 330 000	115	8 720	South Korea	48 400 000	98 400	491	2 030
Finland	5 220 000	338 000	15	64 700	Spain	40 300 000	504 000	80	12 500
France	60 600 000	547 000	110	9 010	Sudan	40 100 000	2 500 000	16	62 300
Gaza Strip	1 370 000	360	3 820	261	Suriname	438 000	163 000	2.7	372 000
Germany	82 400 000	357 000	230	4 330	Sweden	9 000 000	449 000	20	49 900
Greece	10 600 000	131 000	81	12 300	Switzerland	7 480 000	41 200	181	5 510
Greenland	56 300	2 160 000	0.026	38 400 000	Taiwan	22 800 000	35 900	636	1 570
Hong Kong	6 890 000	1 090	6 310	158	Tanzania	36 700 000	945 000	39	25 700
Hungary	10 000 000	93 000	107	9 290	Thailand	65 400 000	514 000	127	7 850
Iceland	296 000	103 000	2.9	347 000	Turkey	69 600 000	780 000	89	11 200
India	1 080 000 000	3 280 000	328	3 040	Ukraine	47 400 000	603 000	78	12 700
Indonesia	241 000 000	1 910 000	126	7 930	United Kingdom	59 500 000	244 000	243	4 110
Iran	68 000 000	1 640 000	41	24 200	USA (ex. Alaska)	295 000 000	8 150 000	36	27 600
Ireland	4 010 000	70 200	57	17 500	Venezuela	25 300 000	912 000	28	35 900
Italy	58 100 000	301 000	192	5 180	Vietnam	83 500 000	329 000	253	3 940
Japan	127 000 000	377 000	337	2 960	Wales	2 910 000	20 700	140	7 110
Kazakhstan	15 100 000	2 710 000	6	178 000	Western Sahara	273 000	266 000	1	974 000
Kenya	33 800 000	582 000	58	17 200	World	6 440 000 000	148 000 000	43	23 100
Latin America	342 000 000	17 800 000	19	52 100	Yemen	20 700 000	527 000	39	25 400
Latvia	2 290 000	64 500	35	28 200	Zambia	11 200 000	752 000	15	66 800
Libya	5 760 000	1 750 000	3.3	305 000					

Table J.5. Regions and their population densities. Populations above 50 million and areas greater than 5 million km² are highlighted. These data are displayed graphically in figure J.1 (p338). Data are from 2005.

K UK energy history

Primary fuel	kWh/d/p	kWh(e)/d/p
Oil	43	
Natural gas	47	
Coal	20	
Nuclear	9	→ 3.4
Hydro		0.2
Other renewables		0.8

Table K.1. Breakdown of primary energy sources in the UK (2004–2006).

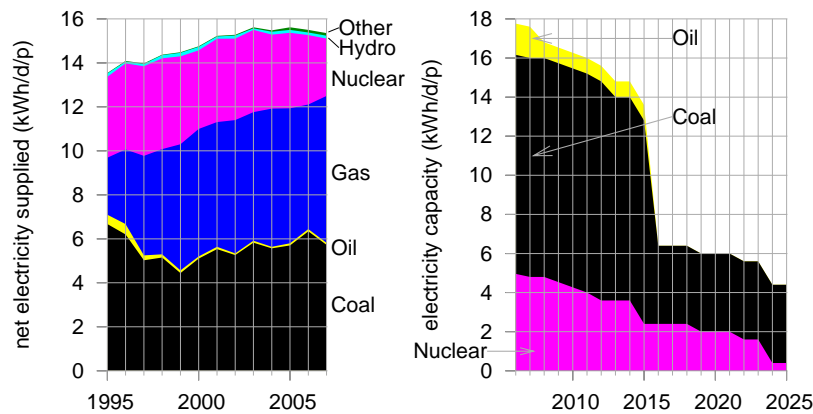


Figure K.2. Left: UK net electricity supplied, by source, in kWh per day per person. (Another 0.9 kWh/d/p is generated and used by the generators themselves.)

Right: the energy gap created by UK power station closures, as projected by energy company EdF. This graph shows the predicted *capacity* of nuclear, coal, and oil power stations, in kilowatt-hours per day per person. The capacity is the maximum deliverable power of a source.

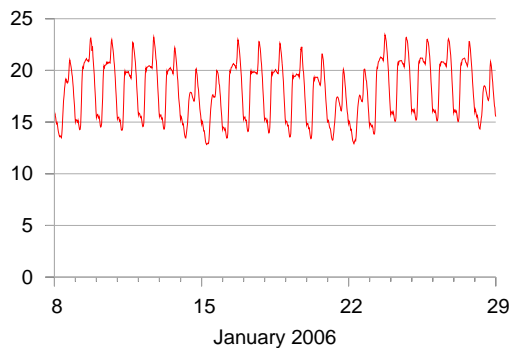


Figure K.3. Electricity demand in Great Britain (in kWh/d per person) during two winter weeks of 2006. The peaks in January are at 6pm each day. (If you'd like to obtain the national demand in GW, the top of the scale, 24 kWh/d per person, is the same as 60 GW per UK.)

	2006	2007
"Primary units" (the first 2 kWh/d)	10.73 p/kWh	17.43 p/kWh
"Secondary units" (the rest)	8.13 p/kWh	9.70 p/kWh

Table K.4. Domestic electricity charges (2006, 2007) for Powergen customers in Cambridge, including tax.

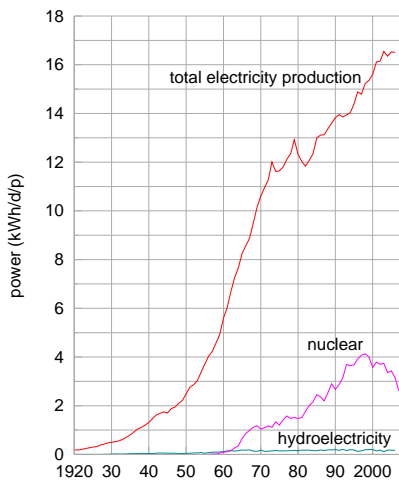


Figure K.5. History of UK production of electricity, hydroelectricity, and nuclear electricity. Powers are expressed “per person” by dividing each power by 60 million.

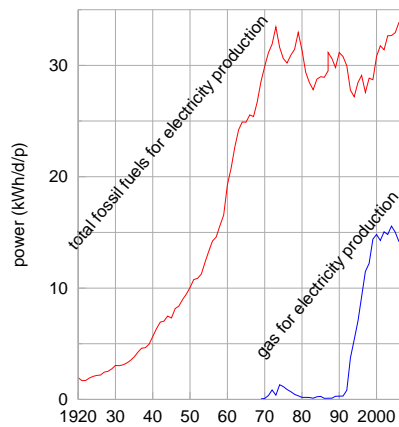


Figure K.6. History of UK use of fossil fuels for electricity production. Powers are expressed “per person” by dividing each power by 60 million.

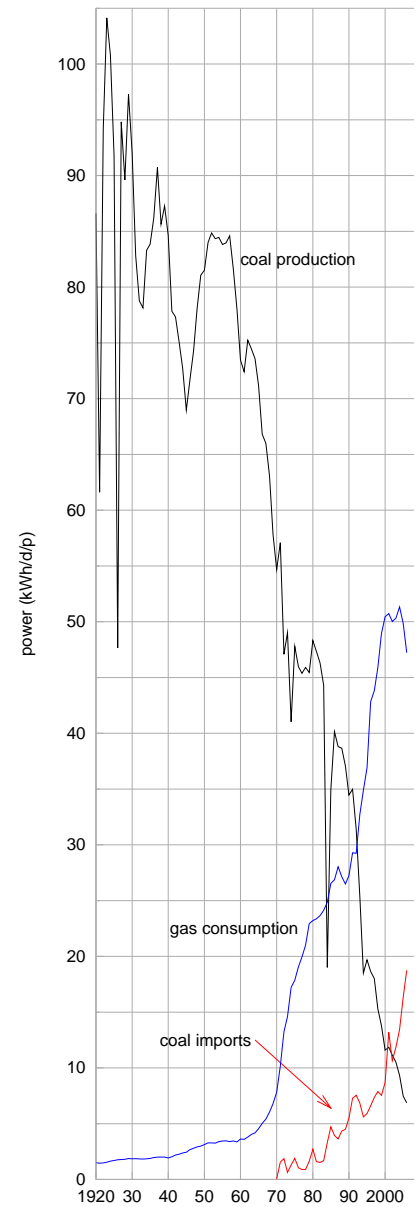


Figure K.7. UK production and imports of coal, and UK consumption of gas. Powers are expressed “per person” by dividing each power by 60 million.

List of web links

This section lists the full links corresponding to each of the tiny URLs mentioned in the text. Each item starts with the page number on which the tiny URL was mentioned. See also <http://tinyurl.com/yh8xse> (or www.inference.phy.cam.ac.uk/sustainable/book/tex/cft.url.html) for a clickable page with all URLs in this book.

If you find a URL doesn't work any more, you may be able to find the page on the Wayback Machine internet archive [[f754](#)].

p tinyURL Full web link.

18 ydoobr www.bbc.co.uk/radio4/news/anyquestions_transcripts_20060127.shtml

18 2jhve6 www.ft.com/cms/s/0/48e334ce-f355-11db-9845-000b5df10621.html

19 25e59w news.bbc.co.uk/1/low/uk_politics/7135299.stm

19 5o7mxk www.guardian.co.uk/environment/2007/dec/10/politics

19 5c4olc www.foe.co.uk/resource/press_releases/green_solutions_undermined_10012008.html

19 2fztd3 www.jalopnik.com/cars/alternative-energy/nov-thats-some-high-quality-h2o-car-runs-on-water-177788.php

19 26e8z news.bbc.co.uk/1/hi/sci/tech/3381425.stm

19 ykhayj politics.guardian.co.uk/terrorism/story/0,,1752937,00.html

20 16y5g www.grida.no/climate/ipcc_tar/wg1/fig3-1.htm

20 5qfkaw www.nap.edu/catalog.php?record_id=12181

21 2z2xg7 assets.panda.org/downloads/2_vs_3_degree_impacts_1oct06_1.pdf

21 yyxq2m www.bp.com/genericsection.do?categoryId=93&contentId=2014442

21 dzcqq www.defra.gov.uk/environment/climatechange/internat/pdf/avoid-dangercc.pdf

21 y98ys5 news.bbc.co.uk/1/hi/business/4933190.stm

30 5647rh www.dft.gov.uk/pgr/statistics/datatablespublications/tsgb/

31 27jdc5 www.dft.gov.uk/pgr/statistics/datatablespublications/energyenvironment/tsgb-chapter3energyandtheenvi1863

31 28abpm corporate.honda.com/environmentology/

31 nmn41 www.simetric.co.uk/si_liquids.htm

31 2hcgdh cta.ornl.gov/data/appendix_b.shtml

34 vxhhj www.cl.cam.ac.uk/research/dtg/weather/

34 tdvml www.phy.hw.ac.uk/resrev/aws/awsarc.htm

36 3fbufz www.ipcc.ch/ipccreports/sres/aviation/004.htm

36 3asmgy news.independent.co.uk/uk/transport/article324294.ece

36 9ehws www.boeing.com/commercial/747family/technical.html

36 3exmgv www.ryanair.com/site/EN/about.php?page=About&sec=environment

36 yrnmm www.grida.no/climate/ipcc/aviation/124.htm

37 36w5gz www.rolls-royce.com/community/downloads/environment04/products/air.html

44 2rqloc www.metoffice.gov.uk/climate/uk/location/scotland/index.html

44 2szckw www.metoffice.gov.uk/climate/uk/stationdata/cambridgedata.txt

45 5hrx1s eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?s01

45 6z9epq www.solarcentury.com/knowledge_base/images/solar_pv_orientation_diagram

47 2t17t6 www.reuk.co.uk/40-Percent-Efficiency-PV-Solar-Panels.htm

47 6hobq2 www.azonano.com/news.asp?newsID=4546

47 21sx6t www.udel.edu/PR/UDaily/2008/jul/solar072307.html

47 62ccou www.nrel.gov/news/press/2008/625.html

48 5hzs5y www.ens-newswire.com/ens/dec2007/2007-12-26-093.asp

48 39z5m5 news.bbc.co.uk/1/hi/world/europe/6505221.stm

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48 2ahecp www.aps.org/meetings/multimedia/upload/The_Status_and_Outlook_for_the_Photovoltaics_Industry_David_E_Carlson.pdf

48 6kqq77 www.defra.gov.uk/erdp/pdfs/ecs/miscanthus-guide.pdf

58 ynzej www.aceee.org/conf/06modeling/azevedo.pdf

64 wbd8o www.ref.org.uk/energydata.php

66 25e59w news.bbc.co.uk/1/low/uk.politics/7135299.stm

66 2t2vjq www.guardian.co.uk/environment/2007/dec/11/windpower.renewableenergy

66 57984r www.businessgreen.com/business-green/news/2205496/critics-question-government

66 6oc3ja www.independent.co.uk/environment/green-living/donnachadh-mccarthy-my-carbonfree-year-767115.html

66 5soql2 www.housebuildersupdate.co.uk/2006/12/eco-bollocks-award-windsave-ws1000.html

66 6g2jm5 www.carbontrust.co.uk/technology/technologyaccelerator/small-wind

79 5h69fm www.thepoultrysite.com/articles/894/economic-approach-to-broiler-production

80 5pwojp www.fertilizer.org/ifa/statistics/STATSIND/pkann.asp

80 5bj8k3 www.walkerscarbonfootprint.co.uk/walkers_carbon_footprint.html

80 3s576h www.permatopia.com/transportation.html

87 6xrm5q www.edf.fr/html/en/decouvertes/voyage/usine/retour-usine.html

94 yx7zm4 www.cancentral.com/funFacts.cfm

94 r22oz www-materials.eng.cam.ac.uk/mpsite/interactive_charts/energy-cost/NS6Chart.html

94 yhrest www.transportation.anl.gov/pdfs/TA/106.pdf

94 y5as53 www.aluminum.org/Content/NavigationMenu/The_Industry/Government_Policy/Energy/Energy.htm

94 y2ktgg www.ssab.com/templates/Ordinary___573.aspx

95 6lbrab www.lindenau-shipyard.de/pages/newsb.html

95 5ctx4k www.wilhelmsen.com/SiteCollectionDocuments/WW_Miljorapport_engelsk.pdf

95 yqbz13 www.normanbaker.org.uk/downloads/Supermarkets_Report_Final_Version.doc

102 yttg7p budget2007.treasury.gov.uk/page_09.htm

102 fcqfw www.mod.uk/DefenceInternet/AboutDefence/Organisation/KeyFactsAboutDefence/DefenceSpending.htm

102 2e4fcs press.homeoffice.gov.uk/press-releases/security-prebudget-report

102 33x5kc www.mod.uk/NR/rdonlyres/95BBA015-22B9-43EF-B2DC-DFE14482A590/0/gep_200708.pdf

102 35ab2c www.dasa.mod.uk/natstats/ukds/2007/c1/table103.html

102 yg5fsj siteresources.worldbank.org/DATASTATISTICS/Resources/GDP.pdf

102 yfgjna www.sipri.org/contents/milap/milex/mex_major_spenders.pdf/download

102 slbae www.wisconsinproject.org/countries/israel/plut.html

102 yh45h8 www.usec.com/v2001_02/HTML/Aboutusec_swu.asp

102 t2948 www.world-nuclear.org/info/inf28.htm

102 2ywee www.globalsecurity.org/wmd/intro/u-centrifuge.htm

112 uzek2 www.dti.gov.uk/energy/inform/dukes/

112 3av4s9 hdr.undp.org/en/statistics/

112 6frj55 news.independent.co.uk/environment/article2086678.ece

129 5qhvcb www.tramwayinfo.com/Tramframe.htm?www.tramwayinfo.com/tramways/Articles/Compair2.htm

134 4qgg8q www.newsweek.com/id/112733/output/print

135 5o5x5m www.cambridgeenergy.com/archive/2007-02-08/cef08feb2007kemp.pdf

135 5o5x5m www.cambridgeenergy.com/archive/2007-02-08/cef08feb2007kemp.pdf

135 5fbeg9 www.cfit.gov.uk/docs/2001/racomp/racomp/pdf/racomp.pdf

135 679rpc www.tfl.gov.uk/assets/downloads/environmental-report-2007.pdf

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137 658ode www.greencarcongress.com/2008/02/mitsubishi-moto.html

139 czjjo corporate.honda.com/environment/fuel_cells.aspx?id=fuel_cells_fcx

139 5a3ryx automobiles.honda.com/fcx-clarify/specifications.aspx

154 yok2nw www.eca.gov.uk/etl/find/_P_Heatpumps/detail.htm?ProductID=9868&FromTechnology=SWaterSourcePackaged

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 160 yhxf8b www.worldenergy.org/wec-geis/publications/reports/ser/coal/coal.asp
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 175 49hcnw www.ace.mmu.ac.uk/Resources/Fact_Sheets/Key_Stage_4/Waste/pdf/02.pdf
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 176 6oby22 www.osti.gov/energycitations/product.biblio.jsp?osti_id=6773271&query_id=0
 176 6312lp pubs.acs.org/cgi-bin/abstract.cgi/jacsat/2002/124/i18/abs/ja003472m.html
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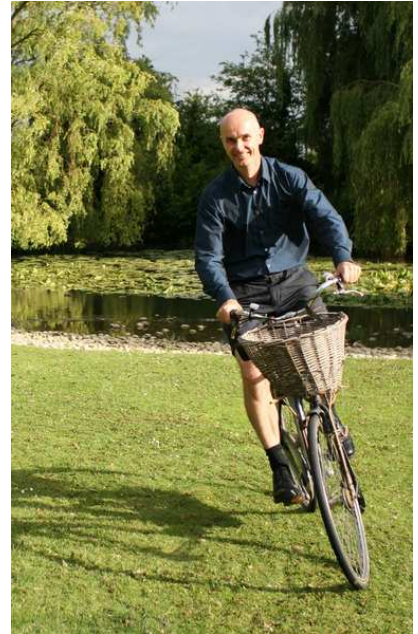
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Sustainable Energy – without the hot air

David JC MacKay

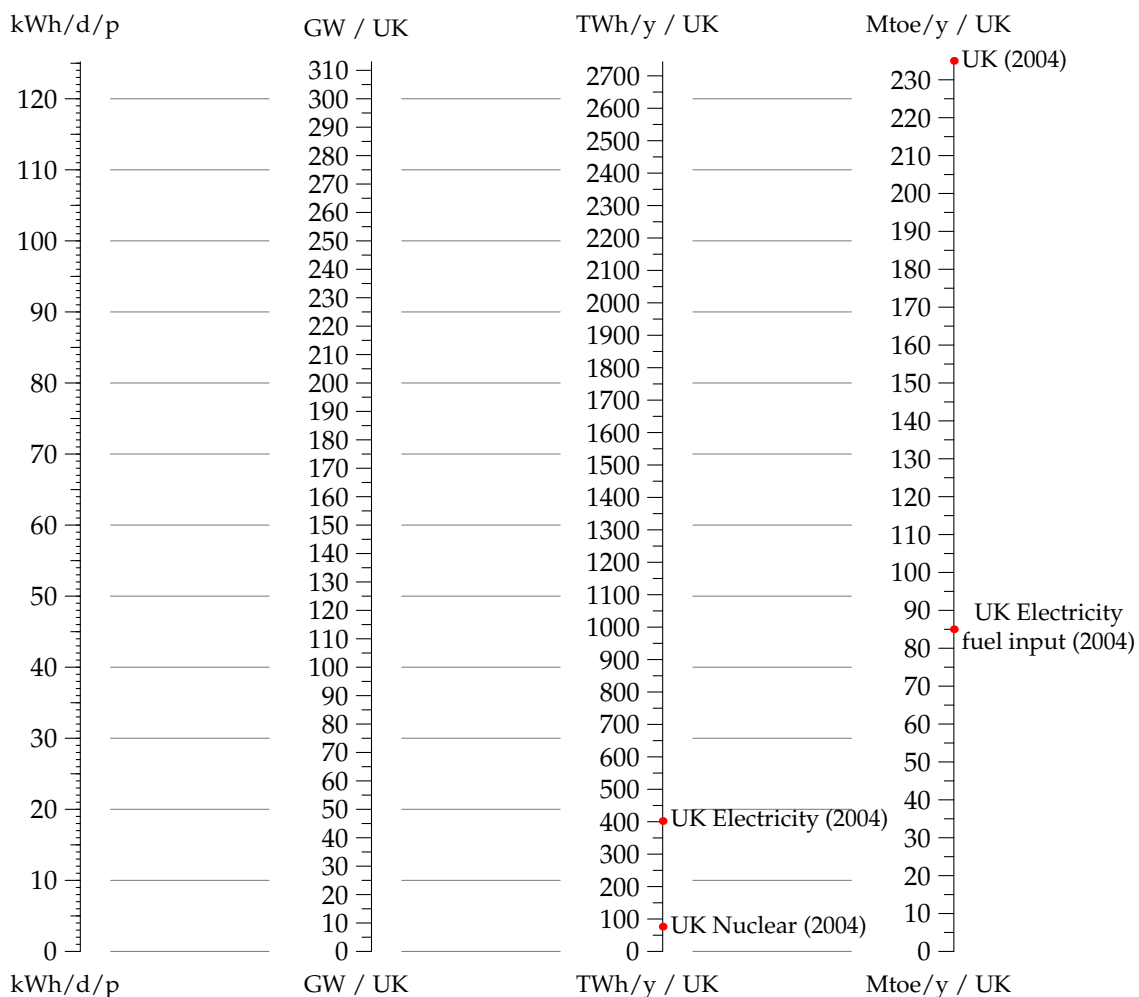
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David MacKay is a Professor in the Department of Physics at the University of Cambridge. He studied Natural Sciences at Cambridge and then obtained his PhD in Computation and Neural Systems at the California Institute of Technology. He returned to Cambridge as a Royal Society research fellow at Darwin College. He is internationally known for his research in machine learning, information theory, and communication systems, including the invention of Dasher, a software interface that enables efficient communication in any language with any muscle. He has taught Physics in Cambridge since 1995. Since 2005, he has devoted much of his time to public teaching about energy. He is a member of the World Economic Forum Global Agenda Council on Climate Change.



The author, July 2008.
Photo by David Stern.

Power translation chart



1 kWh/d the same as $\frac{1}{24}$ kW

GW often used for 'capacity' (peak output)

TWh/y often used for average output

1 Mtoe 'one million tons of oil equivalent'

"UK" = 60 million people

USA energy consumption: 250 kWh/d per person
 Europe energy consumption: 125 kWh/d per person

The most commonly used units in public documents discussing power options are:

terawatt-hours per year (TWh/y).

1000 TWh/y per United Kingdom is roughly equal to 45 kWh/d per person.

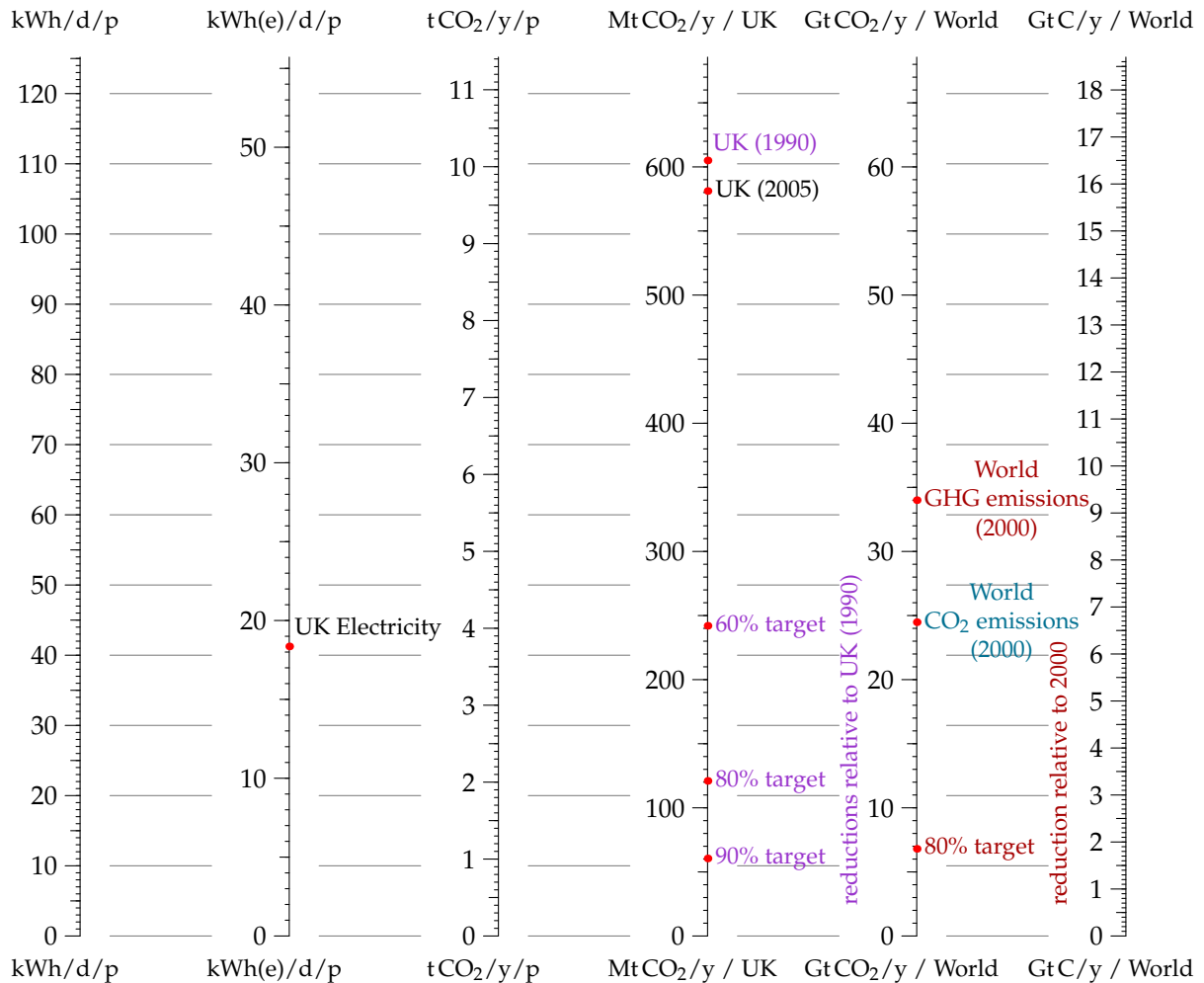
gigawatts (GW).

2.5 GW per UK is 1 kWh/d per person.

million tons of oil equivalent per year (Mtoe/y).

2 Mtoe/y per UK is roughly 1 kWh/d per person.

Carbon translation chart



kWh *chemical* energy exchange rate:
1 kWh ↔ 250 g of CO₂ (oil, petrol)

(for gas, 1 kWh ↔ 200 g)

kWh(e) *electrical* energy is more costly:

1 kWh(e) ↔ 445 g of CO₂ (gas)

(Coal costs twice as much CO₂)

tCO₂ ton of CO₂

MtC million tons of carbon

“UK” = 60 million people

“World” = 6 billion people

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