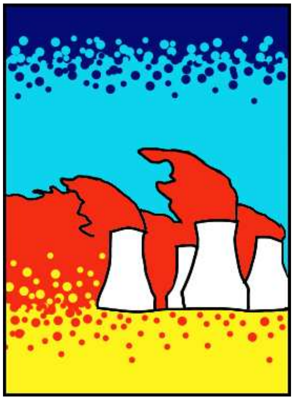
Part IV

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		
energy	one joule	1 J
power	one watt	1 W
force	one newton	1 N
length	one metre	1 m
time	one second	1 s
temperature	one kelvin	1 K

prefix	kilo	mega	giga	tera	peta	exa
symbol	k	M	G	T	P	E
factor	10^3	10^6	10^9	10^{12}	10^{15}	10^{18}

prefix	centi	milli	micro	nano	pico	femto
symbol	c	m	μ	n	p	f
factor	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}

Table I.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	$24 \times 3600\,\text{s} \simeq 10^5\,\text{s}$
	one year	1 y	$365.25 \times 24 \times 3600\,\text{s} \simeq \pi \times 10^7\,\text{s}$
force per mass	kilowatt-hour per ton-kilometre	1 kWh/t-km	$3.6\,\text{m/s}^2$ ($\simeq 0.37g$)

Additional units and symbols

Thing measured	unit name	symbol	value
humans	person	p	
mass	ton	t	1 t = 1000 kg
	gigaton	Gt	$1\,Gt = 10^9 \times 1000\,kg = 1\,Pg$
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 CO_2 for million tons of CO_2.

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 CO_2 emissions of a "home," the official exchange rate appears to be 4 tons CO_2 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.

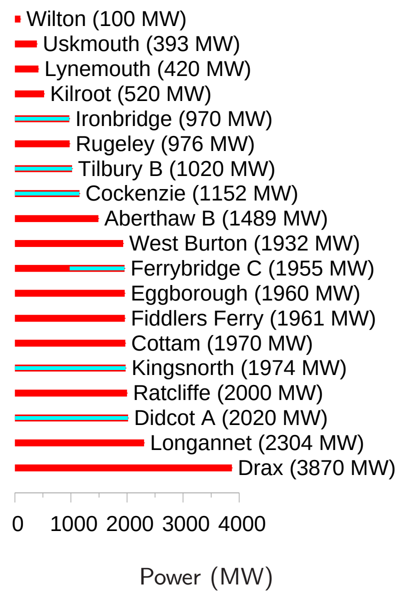


Figure I.2. Powers of Britain's coal power stations. I've highlighted in blue 8 GW of generating capacity that will close by 2015. 2500 MW, shared across Britain, is the same as 1 kWh per day per person.

Cars taken off the road

Some advertisements describe reductions in CO_2 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 Beardie 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 CO_2 per year, which is equivalent to "23 000 cars taken off the road." This statement reveals the exchange rate:

$$\text{"one car taken off the road"} \longleftrightarrow -1.5 \text{ tons per year of } CO_2.$$

Calories

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

$$2500\,\text{kcal} = 3\,\text{kWh} = 10\,000\,\text{kJ} = 10\,\text{MJ}.$$

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 CO_2 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 CO_2 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 = 3.785 l = 0.83 imperial gal. 1 imperial gal = 4.545 l.

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" (10^{15}) 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 7 000 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 0.24 l; but a cup of tea or coffee is usually about 0.18 l. To raise 50 cups of water, at 0.18 l 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 m^3.

"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 m^3.)

Expressing amounts of CO_2 by volume rather than mass is a great way to make them sound big. Should "1 kg of CO_2 per day" sound too small, just say "200 000 litres of CO_2 per year"!

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.

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 m^3. 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 m^3.

A swimming pool has a volume of about 3000 m^3.

One double decker bus has a volume of 100 m^3.

One hot air balloon is 2500 m^3.

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

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

Areas

The area of the earth's surface is 500×10^6 km^2; the land area is 150×10^6 km^2.

My typical British 3-bedroom house has a floor area of 88 m^2. In the USA, the average size of a single-family house is 2330 square feet (216 m^2).

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.

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

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 m^2 of panels might have a power of 1 kWp.

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

1 toe/y = 1.33 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.

	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 I.8. Energy intensity of transport modes in the USA. Source: Weber and Matthews (2008).

Calorific values of fuels

Crude oil: 37 MJ/l; 10.3 kWh/l.
Natural gas: 38 MJ/m^3. (Methane has a density of 1.819 kg/m^3.)
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/m^3. So the heat capacity of air per unit volume is 1.2 kJ/m^3/°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/m^3.

Pressure

Atmospheric pressure: 1 bar $\simeq 10^5$ Pa (pascal). Pressure under 1000 m of water: 100 bar. Pressure under 3000 m of water: 300 bar.

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 CO_2 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.

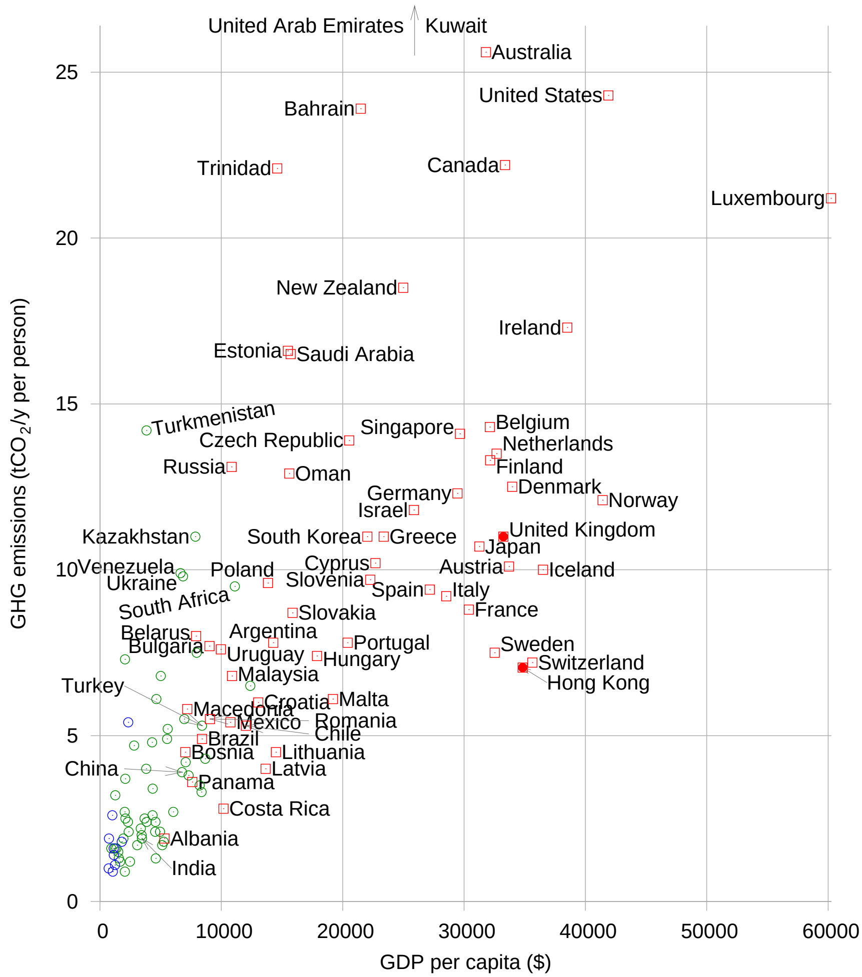


Figure I.11. Greenhouse-gas emissions per capita, versus GDP per capita, in purchasing-power-parity US dollars. Squares show countries having "high human development;" circles, "medium" or "low." See also figures 30.1 (p231) and 18.4 (p105). Source: UNDP Human Development Report, 2007. [3av4s9]

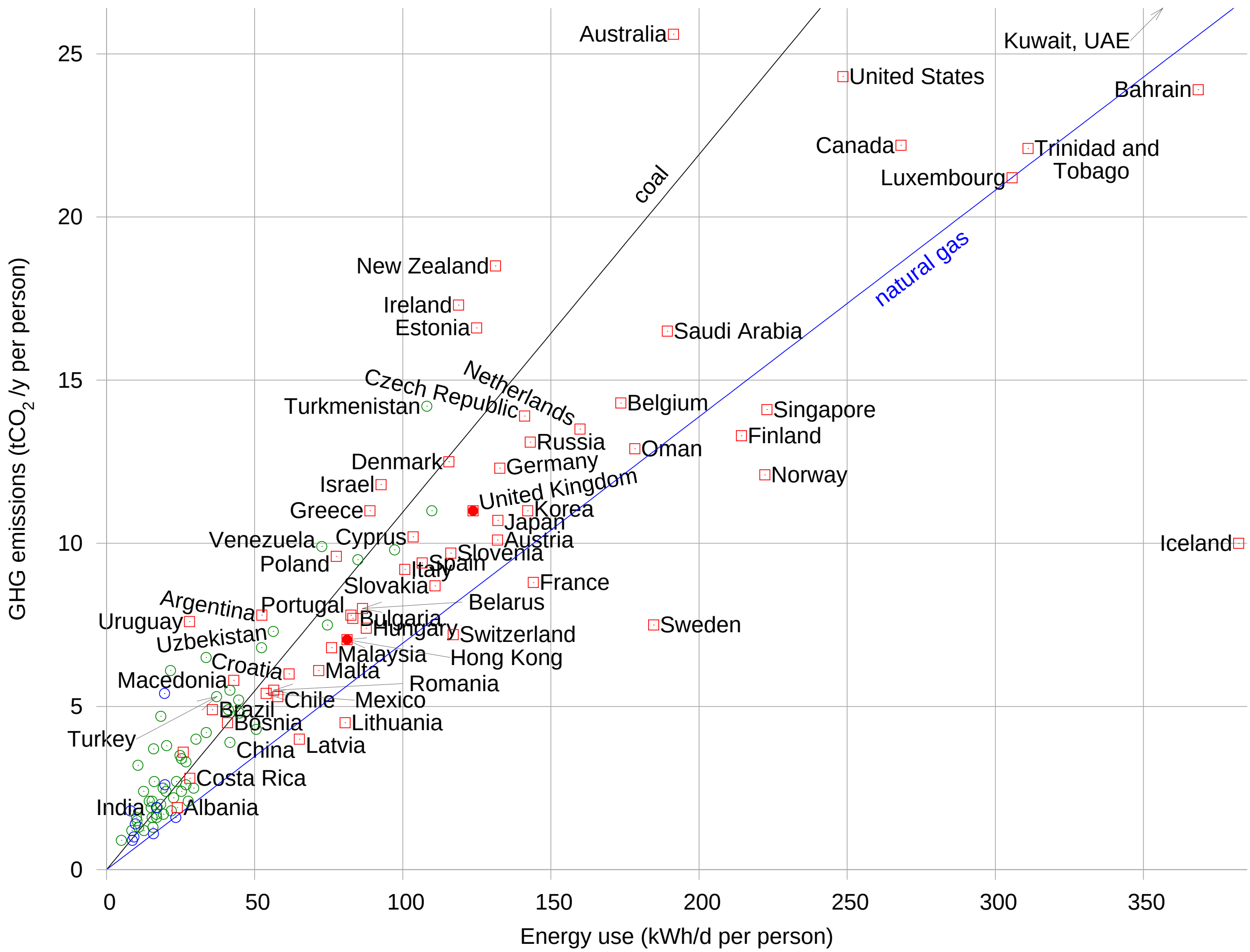


Figure I.12. Greenhouse-gas emissions per capita, versus power consumption per capita. The lines show the emission-intensities of coal and natural gas. Squares show countries having "high human development;" circles, "medium" or "low." See also figures 30.1 (p231) and 18.4 (p105). Source: UNDP Human 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 km^2. Many European countries have about 100 per km^2. At the other extreme, Canada, Australia, and Libya have population densities of about 3 people per km^2. 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.

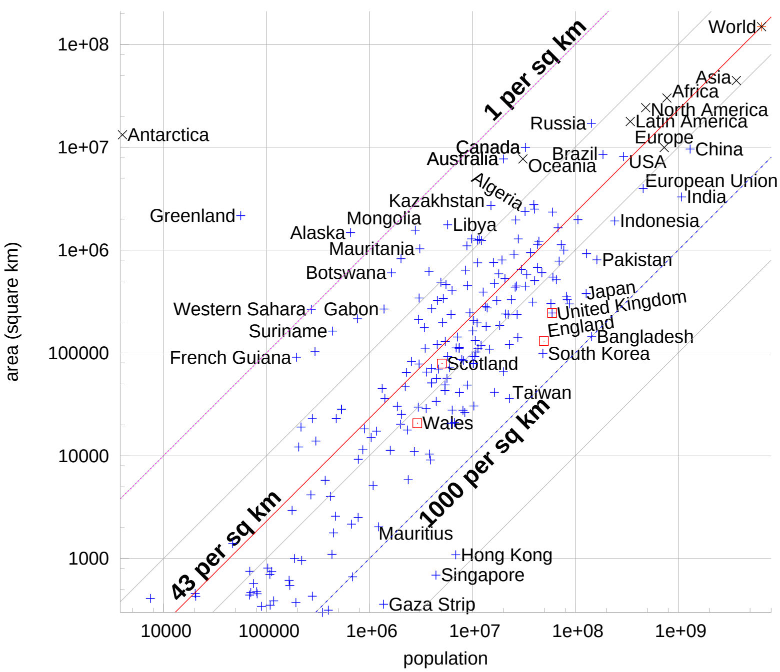


Figure J.1. Populations and areas of countries and regions of the world. Both scales are logarithmic. Each sloping line identifies a population density; countries with highest population density are towards the lower right, and lower population densities are towards the upper left. These data are provided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

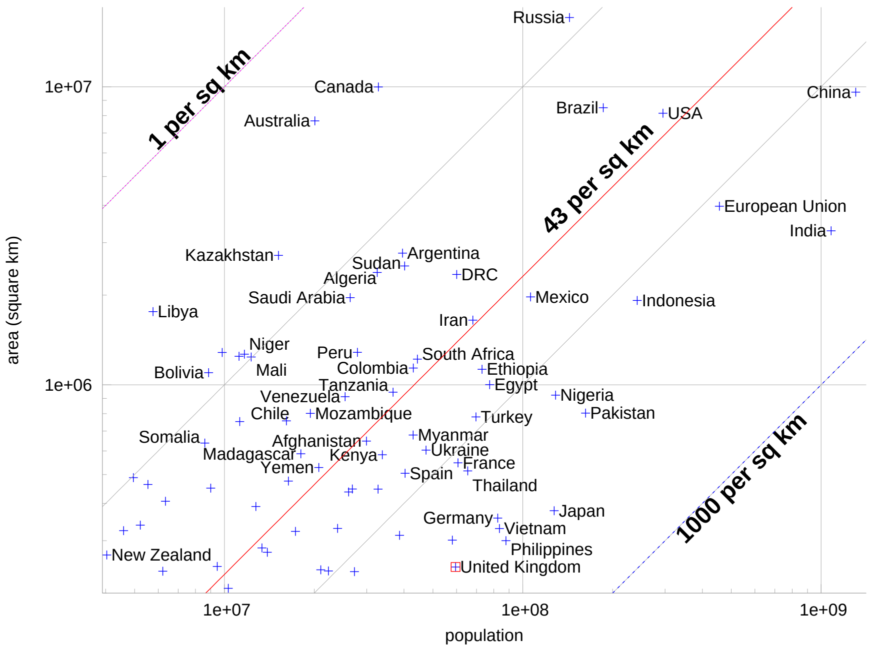


Figure J.2. Populations and areas of countries and regions of the world. Both scales are logarithmic. Sloping lines are lines of constant population density. This figure shows detail from figure J.1 (p338).
These data are provided in tabular form on p341.

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.

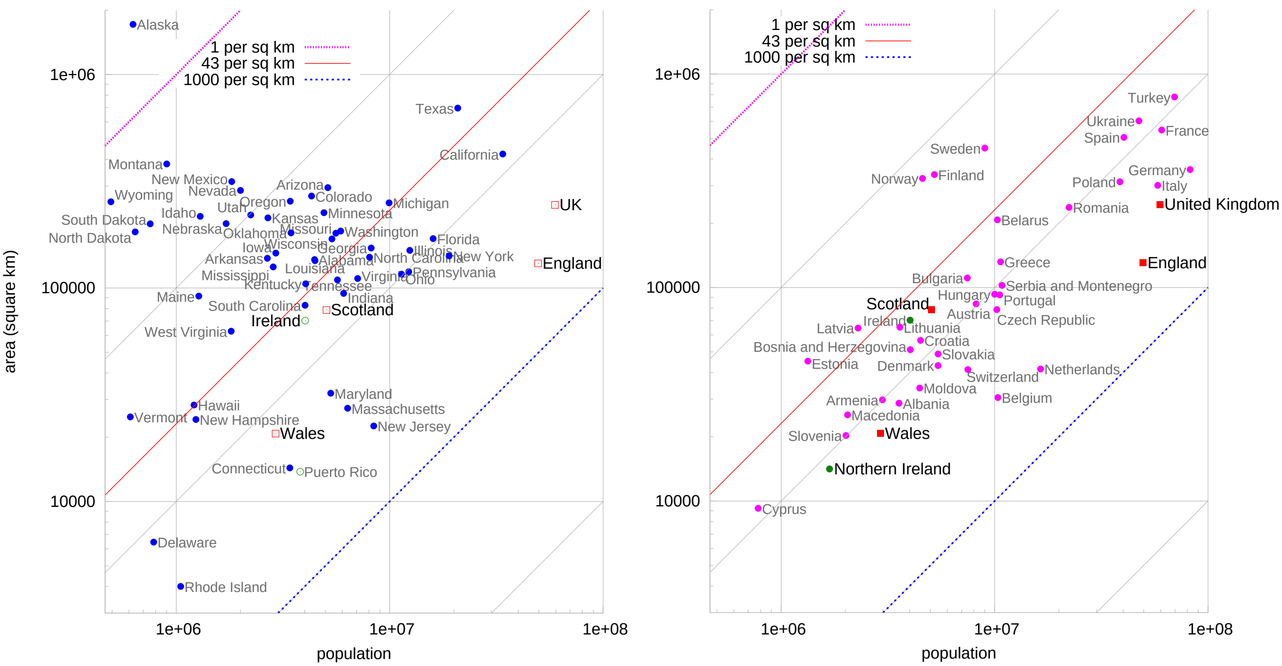


Figure J.4. Populations and areas of the States of America and regions around Europe.

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

Table J.5. Regions and their population densities. Populations above 50 million and areas greater than 5 million km^2 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).

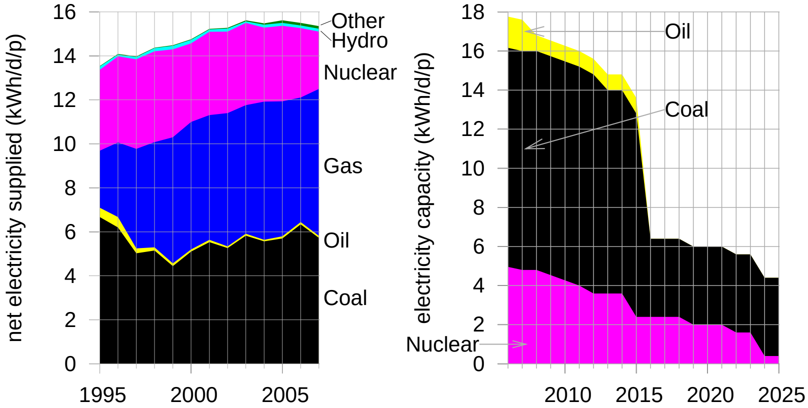


Figure K.2. Left: UK net electricity supplied, by source, in kWh per day per person. (Another 0.9 kWh/d/p is generated and used by the generators themselves.)
Right: the energy gap created by UK power station closures, as projected by energy company EdF. This graph shows the predicted *capacity* of nuclear, coal, and oil power stations, in kilowatt-hours per day per person. The capacity is the maximum deliverable power of a source.

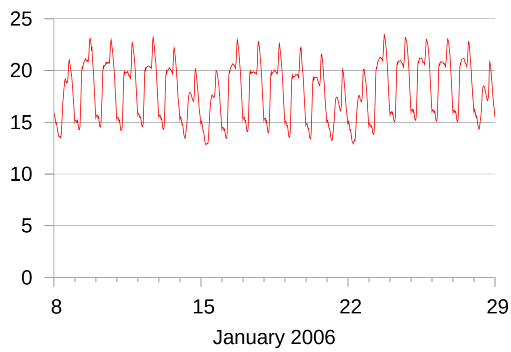


Figure K.3. Electricity demand in Great Britain (in kWh/d per person) during two winter weeks of 2006. The peaks in January are at 6pm each day. (If you'd like to obtain the national demand in GW, the top of the scale, 24 kWh/d per person, is the same as 60 GW per UK.)

	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.

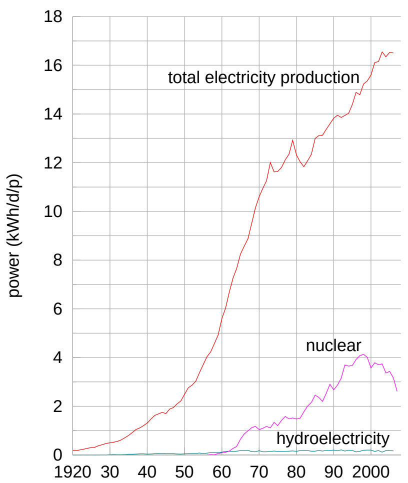


Figure K.5. History of UK production of electricity, hydroelectricity, and nuclear electricity.
Powers are expressed "per person" by dividing each power by 60 million.

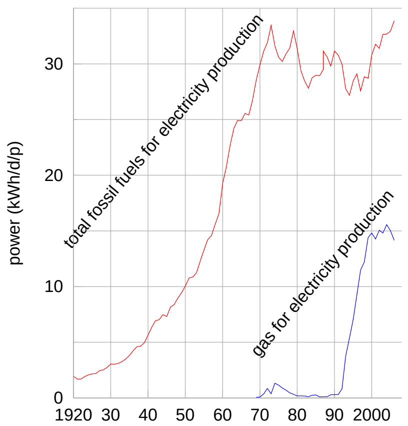


Figure K.6. History of UK use of fossil fuels for electricity production.
Powers are expressed "per person" by dividing each power by 60 million.

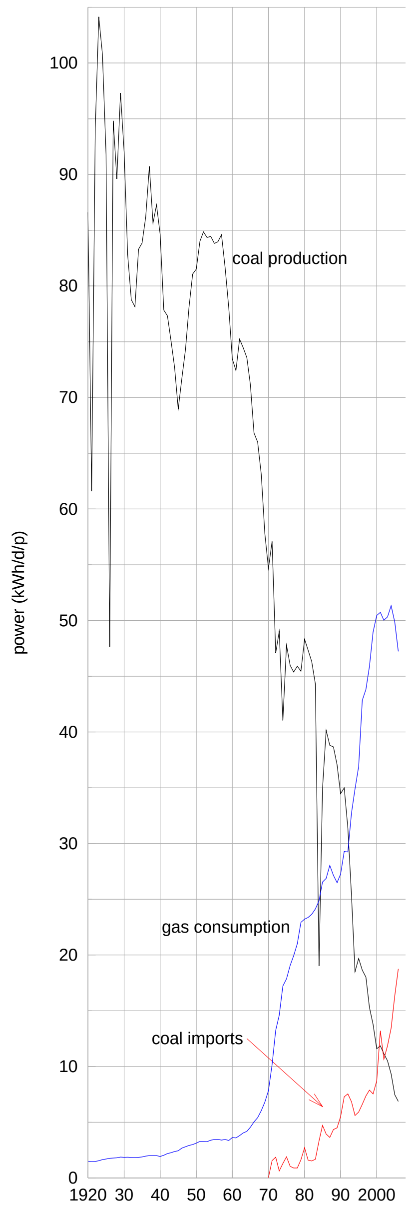


Figure K.7. UK production and imports of coal, and UK consumption of gas.
Powers are expressed "per person" by dividing each power by 60 million.

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/now-thats-some-high-quality-h20-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	l6y5g	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	nmn4l	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	yrnmum	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	5hrxls	eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?+s01
45	6z9epq	www.solarcentury.com/knowledge_base/images/solar_pv_orientation_diagram
47	2tl7t6	www.reuk.co.uk/40-Percent-Efficiency-PV-Solar-Panels.htm
47	6hobq2	www.azonano.com/news.asp?newsID=4546
47	2lsx6t	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

48	2uk8q8	www.powerlight.com/about/press2006_page.php?id=59
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	ynjzej	www.aceee.org/conf/06modeling/azevado.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	yqbzl3	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-DFF14482A590/0/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	2ywzee	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
136	5cp27j	www.eaton.com/EatonCom/ProductsServices/Hybrid/SystemsOverview/HydraulicHLA/index.htm
137	4wm2w4	www.citroenet.org.uk/passenger-cars/psa/berlingo/berlingo-electrique.html
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-clarity/specifications.aspx
154	yok2nw	www.eca.gov.uk/etl/find/_P_Heatpumps/detail.htm?ProductID=9868&FromTechnology=S_WaterSourcePackaged

154	2dtx8z	www.eca.gov.uk/NR/rdonlyres/6754FE19-C697-49DA-B482-DA9426611ACF/0/ETCL2007.pdf
154	2fd8ar	www.geothermalint.co.uk/commercial/hydronicheatpumpranges.html
159	5kpjk8	blogs.reuters.com/environment/2008/09/09/a-silver-bullet-or-just-greenwash/
159	yebuk8	www.dti.gov.uk/energy/sources/coal/index.html
160	yhxf8b	www.worldenergy.org/wec-geis/publications/reports/ser/coal/coal.asp
160	e2m9n	www.coal.gov.uk/resources/cleanercoaltechnologies/ucgoverview.cfm
173	5qntkb	www.world-nuclear.org/info/reactors.htm
174	y3wnzr	npc.sarov.ru/english/digest/132004/appendix8.html
174	32t5zt	web.ift.uib.no/~lillestol/Energy_Web/EA.html
174	2qr3yr	documents.cern.ch/cgi-bin/setlink?base=generic&categ=public&id=cer-0210391
174	ynk54y	doc.cern.ch//archive/electronic/other/generic/public/cer-0210391.pdf
174	yl7tkm	minerals.usgs.gov/minerals/pubs/mcs/1999/mcs99.pdf
174	yju4a4	www.uic.com.au/nip67.htm
175	yeyr7z	taylorandfrancis.metapress.com/index/W7241163J23386MG.pdf
175	4f2ekz	www.publications.parliament.uk/pa/cm199900/cmhansrd/vo000505/text/00505w05.htm
175	2k8y7o	www.nei.org/resourcesandstats/
175	3pvf4j	www.sustainableconcrete.org.uk/main.asp?page=210
175	4r7zpg	csereport2005.bluescopesteel.com/
175	49hcnw	www.ace.mmu.ac.uk/Resources/Fact_Sheets/Key_Stage_4/Waste/pdf/02.pdf
175	3kduo7	www.esrcsocietytoday.ac.uk/ESRCInfoCentre/facts/UK/index29.aspx?ComponentId=7104&SourcePageId=18130
176	69vt8r	www.osti.gov/energycitations/product.biblio.jsp?osti_id=7200593
176	6oby22	www.osti.gov/energycitations/product.biblio.jsp?osti_id=6773271&query_id=0
176	63l2lp	pubs.acs.org/cgi-bin/abstract.cgi/jacsat/2002/124/i18/abs/ja003472m.html
176	wnchw	www.feasta.org/documents/wells/contents.html?one/horelacy.html
176	shrln	www.enviros.com/vrepository/
201	2wmuw7	news.yahoo.com/s/ap/20071231/ap_on_hi_te/solar_roads;_ylt=AuEFouXxz16nP8MRlInTJMms0NUE
201	2hxf6c	www.eirgrid.com/EirGridPortal/DesktopDefault.aspx?tabid=WindGenerationCurve&TreeLinkModID=1451&TreeLinkItemID=247
201	2l99ht	www.reuters.com/article/domesticNews/idUSN2749522920080228
201	3x2kvv	www.reuters.com/article/rbssIndustryMaterialsUtilitiesNews/idUSL057816620080305
202	5o2xgu	www.esru.strath.ac.uk/EandE/Web_sites/03-04/wind/content/storageavailable.html
202	2n3pmb	www.dynamicdemand.co.uk/pdf_fridge_test.pdf
202	2k8h4o	www.int.iol.co.za/index.php?art_id=vn20080201045821205C890035
202	5cp27j	www.eaton.com/EatonCom/ProductsServices/Hybrid/SystemsOverview/HydraulicHLA/index.htm
202	2sxlyj	www.batteryuniversity.com/partone-3.htm
202	ktd7a	www.vrbpower.com/docs/news/2006/20060830-PR-TapburySale-IrelandWindfarm.pdf
202	627ced	www.vrbpower.com/docs/whitepapers/SEItechpaper1.pdf
202	5fasl7	www.indexmundi.com/en/commodities/minerals/vanadium/vanadium_t7.html
202	2wmuw7	news.yahoo.com/s/ap/20071231/ap_on_hi_te/solar_roads;_ylt=AuEFouXxz16nP8MRlInTJMms0NUE
213	5os7dy	tinyurl.com/5os7dy
213	yrw2oo	tinyurl.com/yrw2oo
217	6eoyhg	news.bbc.co.uk/1/hi/uk/7215688.stm
217	yu8em5	www.foe.co.uk/resource/reports/paying_for_better_transport.pdf
219	3x2cr4	news.bbc.co.uk/1/hi/england/london/6151176.stm
219	2dd4mz	news.bbc.co.uk/1/low/uk_politics/6391075.stm
219	7vlxp	www.lse.ac.uk/collections/pressAndInformationOffice/newsAndEvents/archives/2005/IDCard_FinalReport.htm
219	6x4nvu	www.statoil.com/statoilcom/svg00990.nsf?opendatabase&artid=F5255D55E1E78319C1256FEF0044704B
219	39g2wz	www.dillinger.de/dh/referenzen/linepipe/01617/index.shtml.en
219	3ac8sj	www.hydro.com/ormenlange/en/
219	y7kg26	www.politics.co.uk/issue-briefs/economy/taxation/tobacco-duty/tobacco-duty-$366602.htm
219	r9fcf	en.wikipedia.org/wiki/War_on_Drugs

221	ysncks	news.bbc.co.uk/1/low/uk_politics/6205174.stm
221	2vq59t	www.boston.com/news/globe/editorial_opinion/oped/articles/2007/08/01/the_63_billion_sham/
221	ym46a9	https://www.cia.gov/cia/publications/factbook/print/xx.html
221	99bpt	www.guardian.co.uk/Iraq/Story/0,2763,1681119,00.html
221	2bmuod	www.guardian.co.uk/environment/2007/aug/13/renewableenergy.energy
221	3g8nn8	image.guardian.co.uk/sys-files/Guardian/documents/2007/08/13/RenewablesTargetDocument.pdf
221	3jo7q2	www.viewsofscotland.org/library/docs/HoL_STC_RE_Practicalities_04.pdf
230	2ykfgw	www.guardian.co.uk/environment/2007/jan/09/travelsenvironmentalimpact.greenpolitics
230	2nsvx2	www.number-10.gov.uk/output/Page10300.asp
230	yxq5xk	commentisfree.guardian.co.uk/george_monbiot/2007/01/an_open_letter_to_the_prime_mi.html
238	3doaeg	web.archive.org/web/20040401165322/members.cox.net/weller43/sunshine.htm
239	3lcw9c	knol.google.com/k/-/-/15x31uzlqeo5n/1
248	voxbz	news.bbc.co.uk/1/low/business/6247371.stm
248	yofchc	news.bbc.co.uk/1/low/uk/7053903.stm
248	3e28ed	www.grida.no/climate/ipcc_tar/wg1/118.htm
258	2bhu35	www.lafn.org/~dave/trans/energy/rail_vs_auto_EE.html
262	6by8x	encarta.msn.com/encyclopedia_761553622/Internal-Combustion_Engine.html
262	348whs	www.cleangreencar.co.nz/page/prius-petrol-engine
266	ydt7uk	www.nrel.gov/business_opportunities/pdfs/31235sow.pdf
266	yaoonz	www.windpower.org/en/tour/wres/shear.htm
267	6o86ec	www.londonarray.com/london-array-project-introduction/offshore/
268	6bkvbn	www.timesonline.co.uk/tol/news/world/asia/article687157.ece
268	yekdaa	www.windpower.org/en/stat/betzpro.htm
268	ymfbsn	www.windpower.org/en/tour/wres/powdensi.htm
268	ypvbvd	www.ref.org.uk/images/pdfs/UK_Wind_Phase_1_web.pdf
268	wbd8o	www.ref.org.uk/energydata.php
277	33ptcg	www.stevefossett.com/html/main_pages/records.html
278	6r32hf	www.theaustralian.news.com.au/story/0,25197,23003236-23349,00.html
282	2af5gw	www.airliners.net/info/stats.main?id=100
282	32judd	www.wildanimalsonline.com/birds/wanderingalbatross.php
282	2qbquv	news.bbc.co.uk/1/low/sci/tech/6988720.stm
282	5h6xph	www.goldcoastyachts.com/fastcat.htm
282	4p3yco	www.fas.org/man/dod-101/sys/ship/row/rus/903.htm
288	3ap7lc	www.biocap.ca/files/Ont_bioenergy_OPA_Feb23_final.pdf
288	4hamks	www.methanetomarkets.org/resources/landfills/docs/uk_lf_profile.pdf
296	65h3cb	www.dorset-technical-committee.org.uk/reports/U-values-of-elements-Sept-2006.pdf
298	5dhups	www.arct.cam.ac.uk/UCPB/Place.aspx?rid=943658&p=6&ix=8&pid=1&prcid=27&ppid=201
321	2bqapk	wwwphys.murdoch.edu.au/rise/reslab/resfiles/tidal/text.html
322	r22oz	www-materials.eng.cam.ac.uk/mpsite/interactive_charts/energy-cost/NS6Chart.html
325	3kmcks	www.yourhome.gov.au/technical/index.html
324	3kmcks	www.yourhome.gov.au/technical/index.html
333	3b7zdf	www.communities.gov.uk/publications/planningandbuilding/generalizedlanduse
336	3av4s9	hdr.undp.org/en/statistics/
344	f754	www.archive.org/web/web.php

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Index

Sustainable Energy – without the hot air

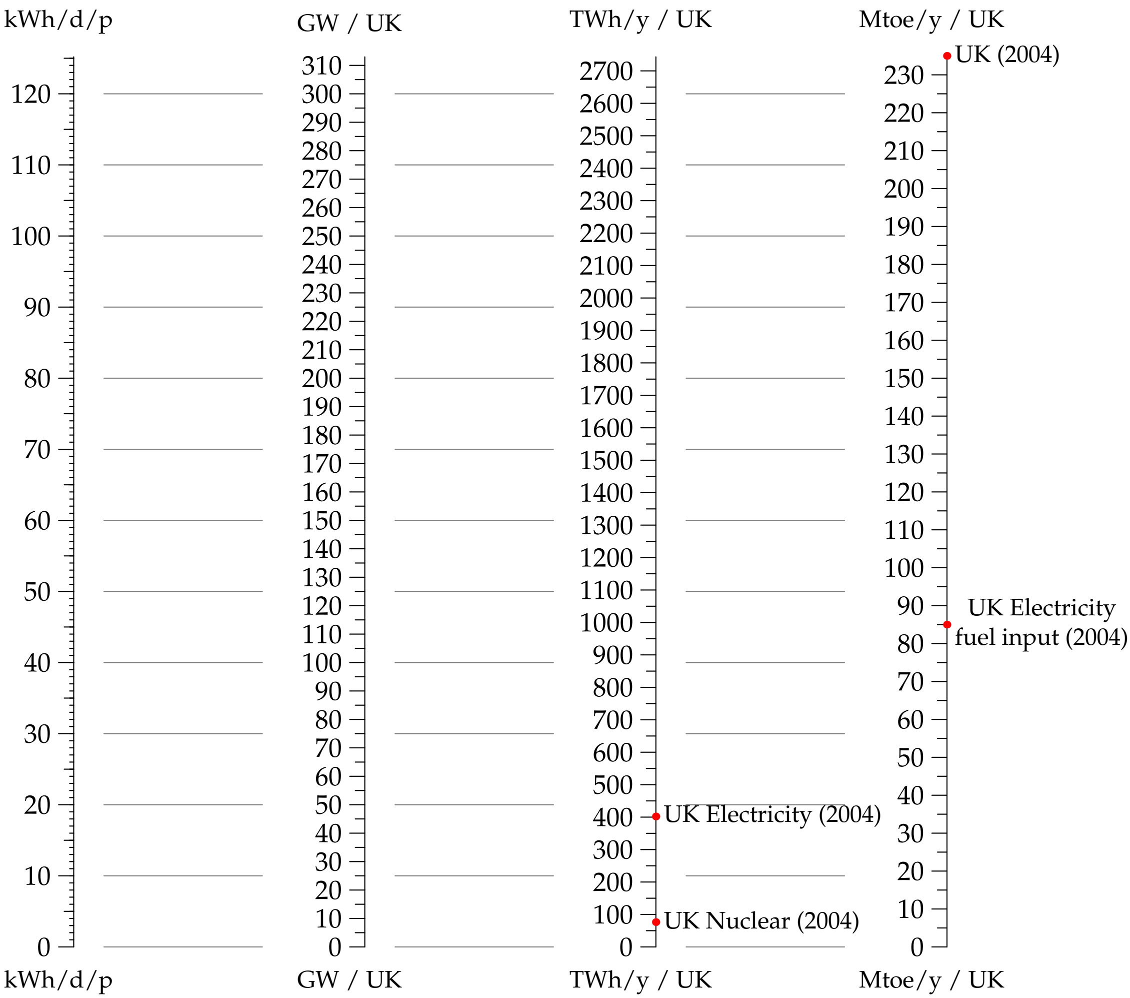
David JC MacKay

About the author

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



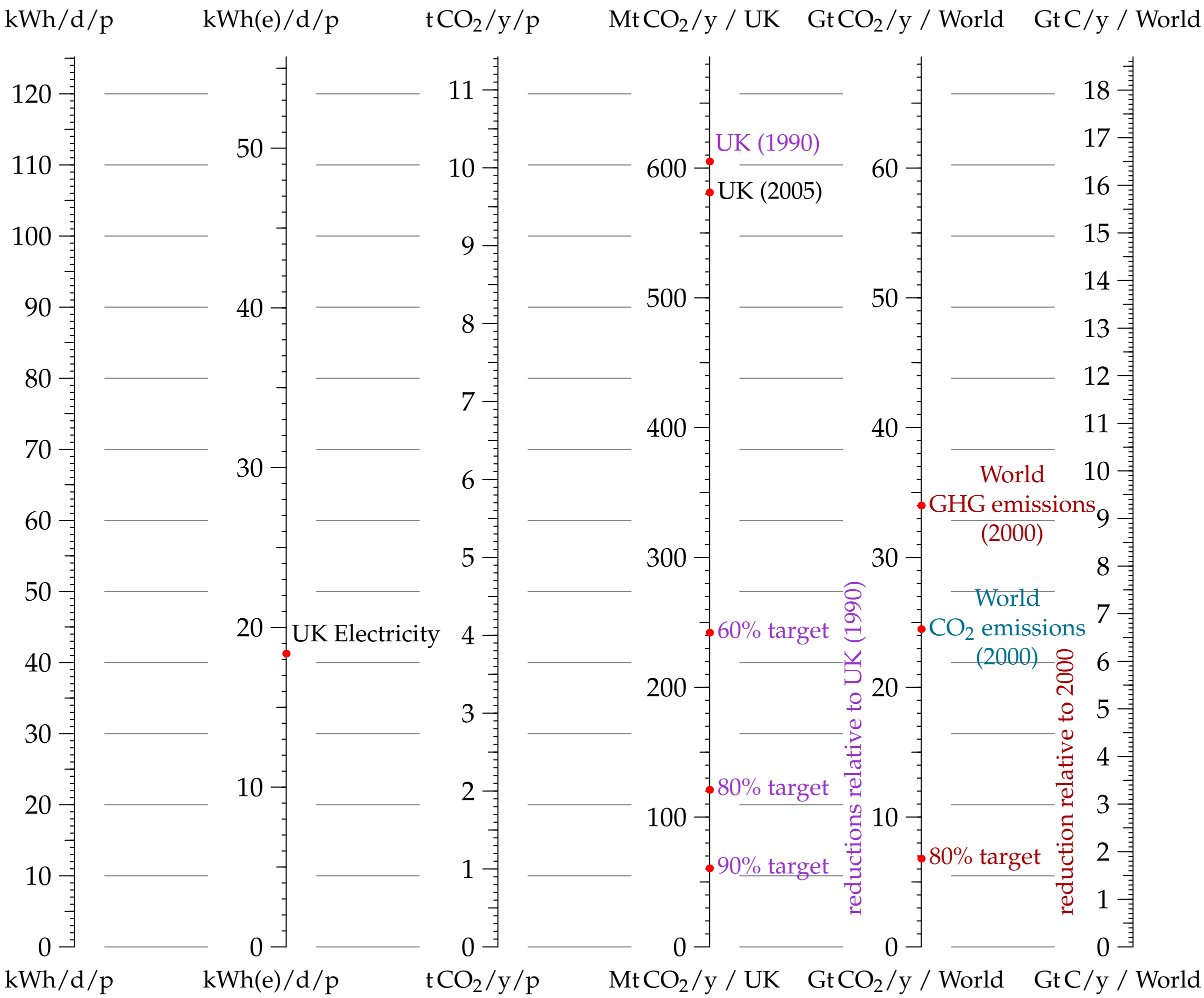
1 kWh/d	the same as 1/24 kW
GW	often used for '**capacity**' (peak output)
TWh/y	often used for average output
1 Mtoe	'one million tons of oil equivalent'

"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 CO_2 (oil, petrol)
	(for gas, 1 kWh ↔ 200 g)
kWh(e)	*electrical* energy is more costly:
	1 kWh(e) ↔ 445 g of CO_2 (gas)
	(Coal costs twice as much CO_2)
t CO_2	ton of CO_2
Mt C	million tons of carbon

"UK" = 60 million people
"World" = 6 billion people

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