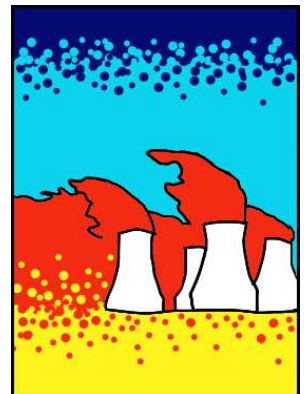


Part IV

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 = $21\,000 \text{ km}^2$
	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.

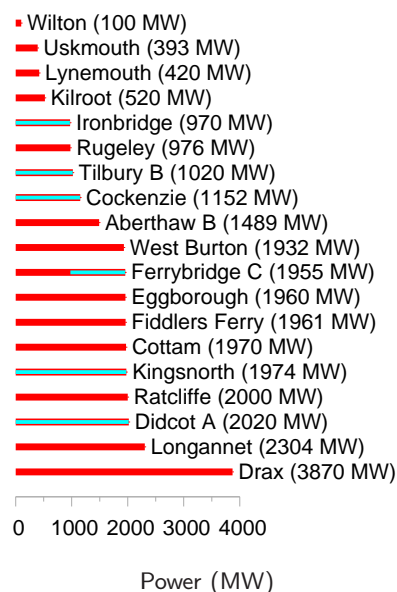


Figure I.2. Powers of Britain’s coal power stations. I’ve highlighted in blue 8 GW of generating capacity that will close by 2015. 2500 MW, shared across Britain, is the same as 1 kWh per day per person.

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 1.6. 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 1.7. 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.

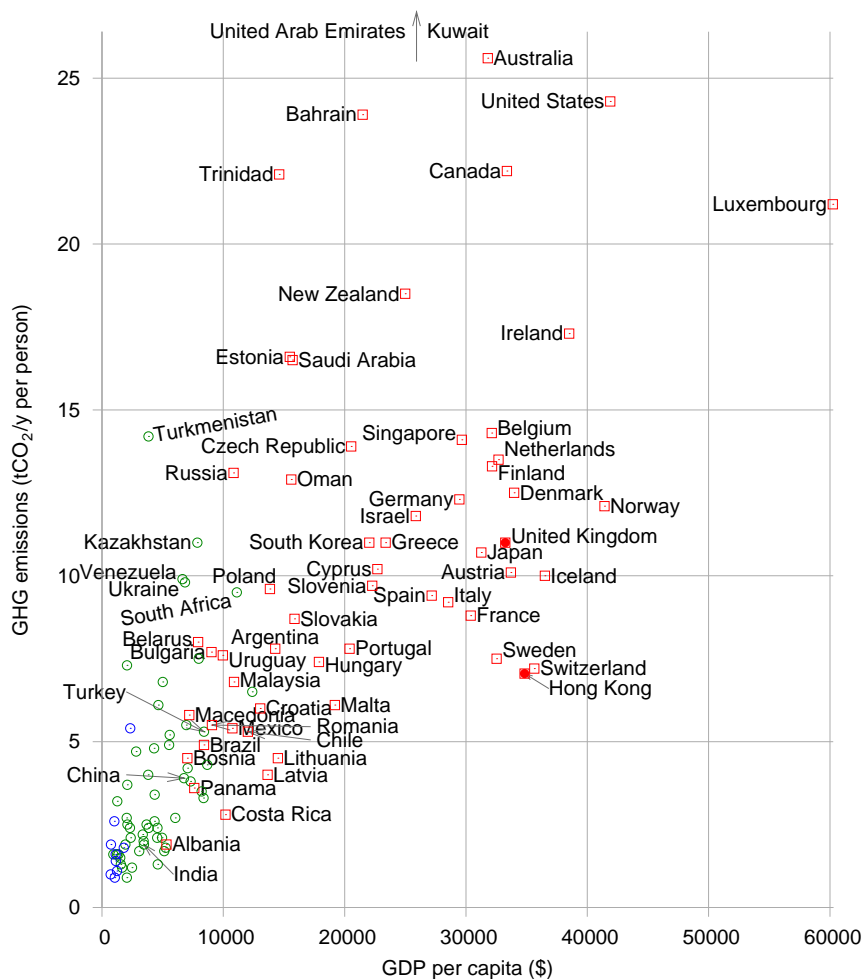


Figure I.11. Greenhouse-gas emissions per capita, versus GDP per capita, in purchasing-power-parity US dollars. Squares show countries having “high human development;” circles, “medium” or “low.” See also figures 30.1 (p231) and 18.4 (p105). Source: UNDP Human Development Report, 2007. [3av4s9]

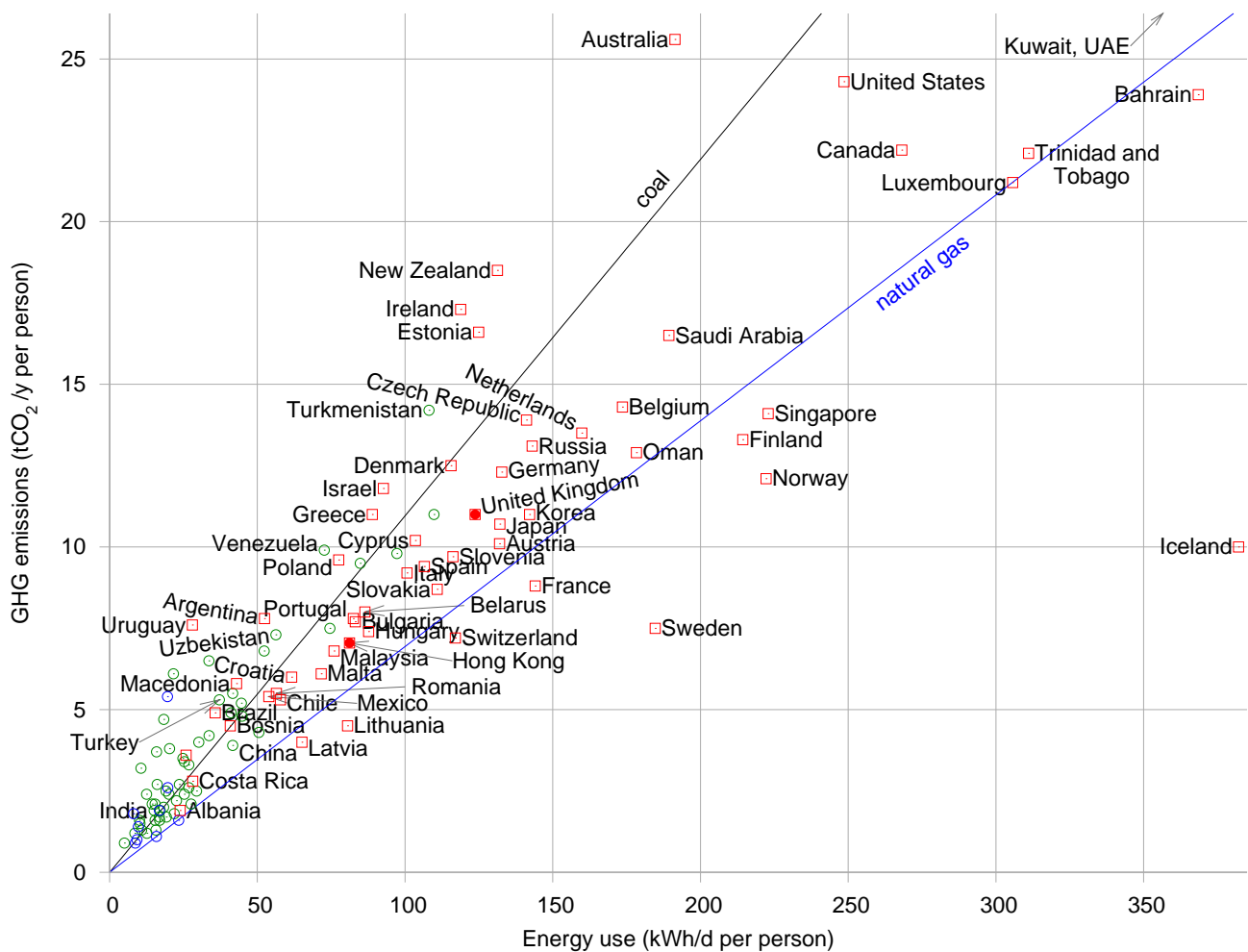


Figure I.12. Greenhouse-gas emissions per capita, versus power consumption per capita. The lines show the emission-intensities of coal and natural gas. Squares show countries having “high human development;” circles, “medium” or “low.” See also figures 30.1 (p231) and 18.4 (p105). Source: UNDP Human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

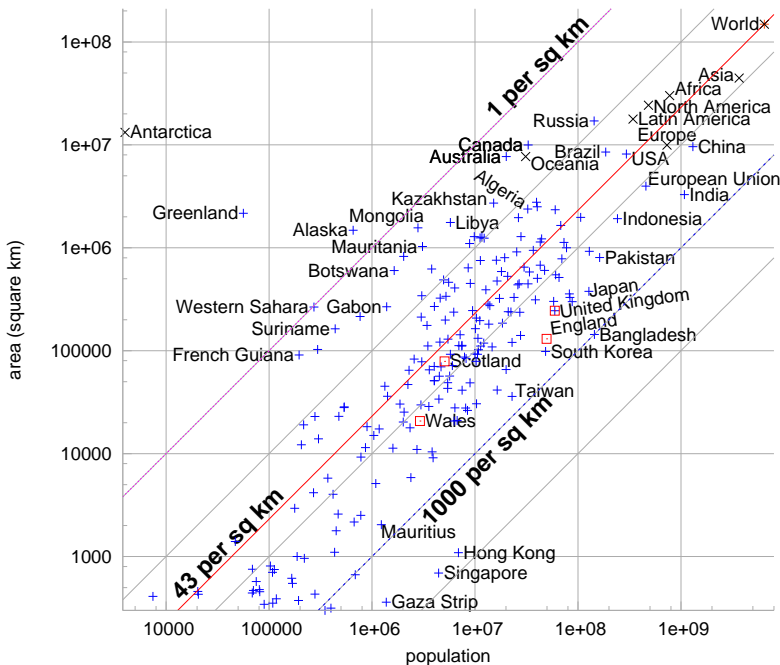


Figure J.1. Populations and areas of countries and regions of the world. Both scales are logarithmic. Each sloping line identifies a population density; countries with highest population density are towards the lower right, and lower population densities are towards the upper left. These data are provided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

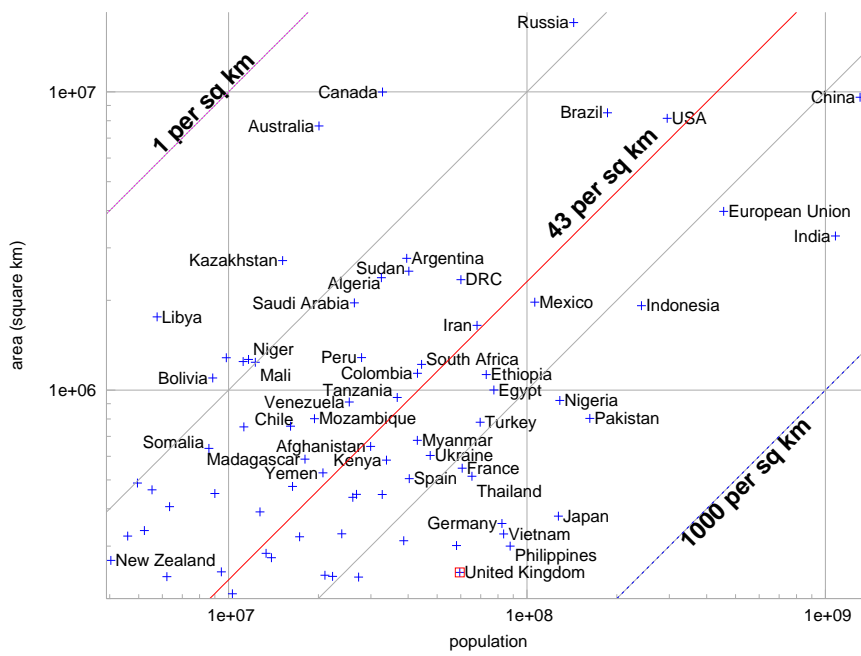


Figure J.2. Populations and areas of countries and regions of the world. Both scales are logarithmic. Sloping lines are lines of constant population density. This figure shows detail from figure J.1 (p338). These data are provided in tabular form on p341.

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.

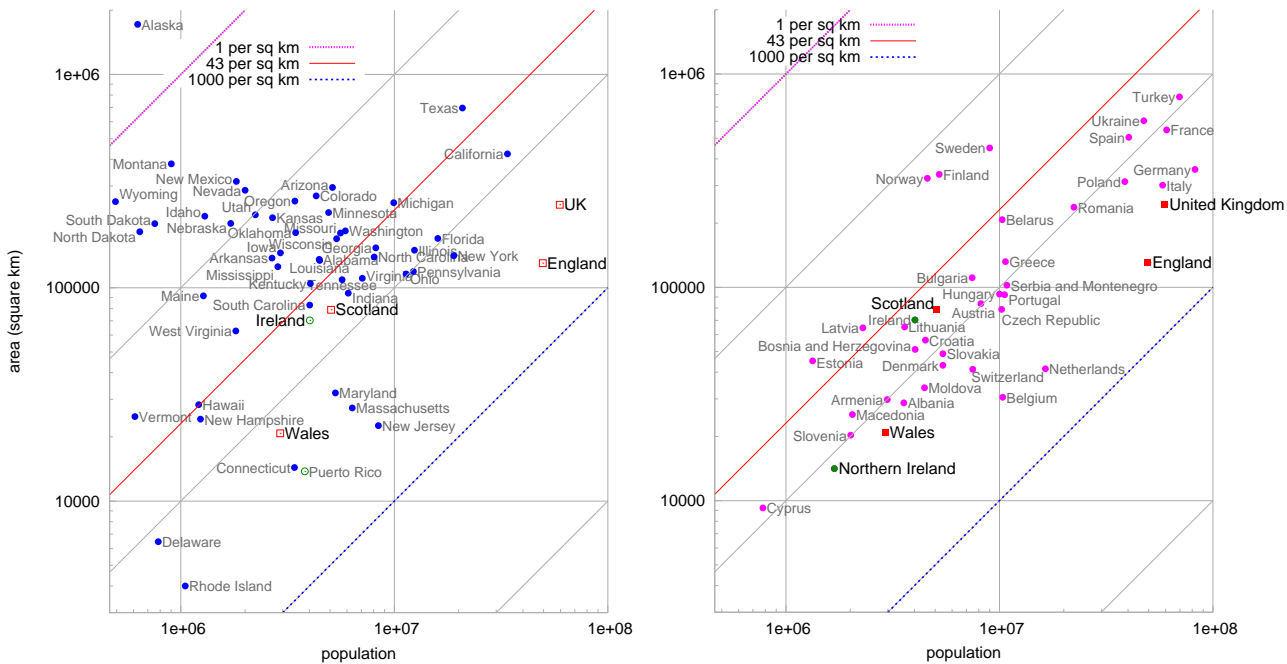


Figure J.4. Populations and areas of the States of America and regions around Europe.

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).

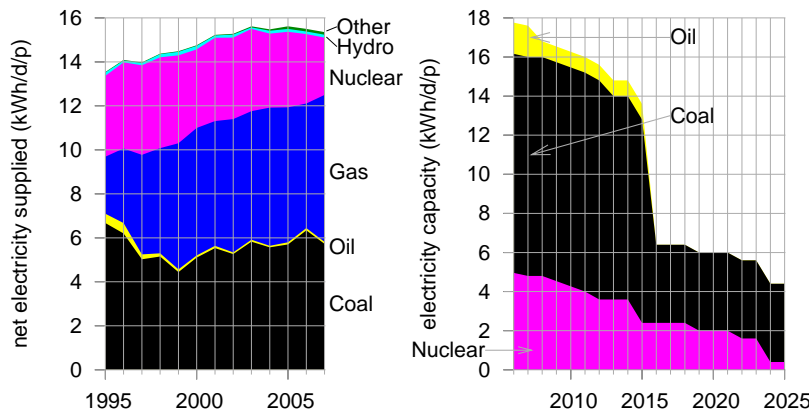


Figure K.2. Left: UK net electricity supplied, by source, in kWh per day per person. (Another 0.9 kWh/d/p is generated and used by the generators themselves.)

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.

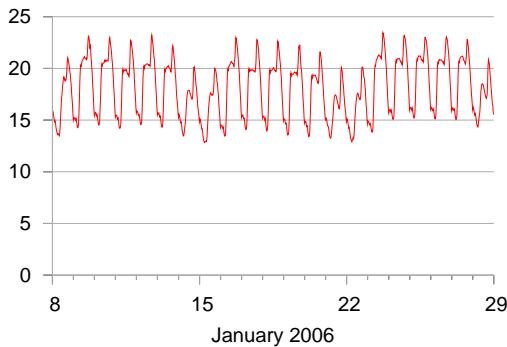


Figure K.3. Electricity demand in Great Britain (in kWh/d per person) during two winter weeks of 2006. The peaks in January are at 6pm each day. (If you'd like to obtain the national demand in GW, the top of the scale, 24 kWh/d per person, is the same as 60 GW per UK.)

	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.

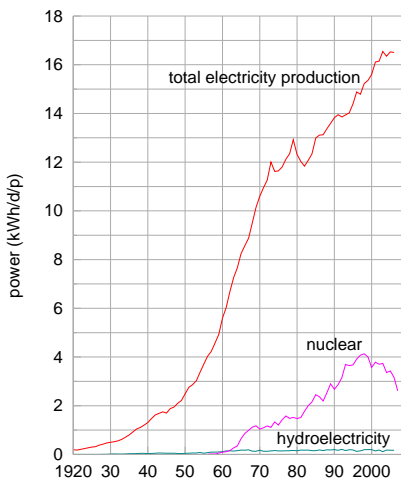


Figure K.5. History of UK production of electricity, hydroelectricity, and nuclear electricity. Powers are expressed “per person” by dividing each power by 60 million.

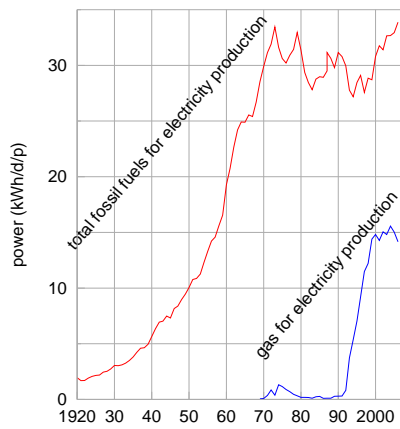


Figure K.6. History of UK use of fossil fuels for electricity production. Powers are expressed “per person” by dividing each power by 60 million.

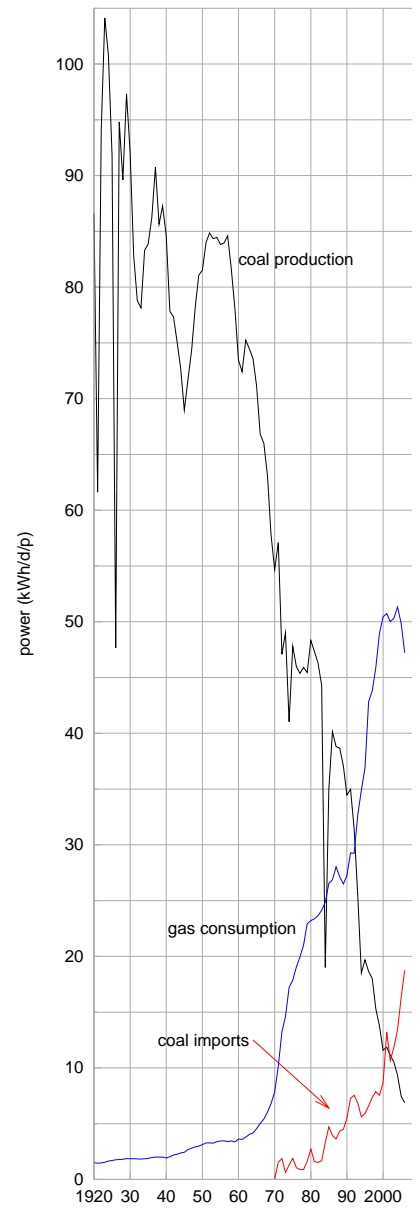


Figure K.7. UK production and imports of coal, and UK consumption of gas. Powers are expressed “per person” by dividing each power by 60 million.

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	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	yrmnum	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

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 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 r2zoz 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 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=SWaterSourcePackaged

154 2dtx8z www.eca.gov.uk/NR/rdonlyres/6754FE19-C697-49DA-B482-DA9426611ACF/0/ETCL2007.pdf
 154 2fd8ar www.geothermalint.co.uk/commercial/hydronecheatpumpranges.html
 159 5kpk8 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 yhx8b www.worldenergy.org/wec-geis/publications/reports/ser/coal/coal.asp
 160 e2m9n www.coal.gov.uk/resources/cleanercoalechnologies/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 y17tkm 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 6312lp 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=AuEFouXxz16nP8MR1InTJMms0NUE
 201 2hxf6c www.eirgrid.com/EirGridPortal/DesktopDefault.aspx?tabid=WindGenerationCurve&TreeLinkModID=1451&TreeLinkItemID=247
 201 2199ht 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
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 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
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 217 yu8em5 www.foe.co.uk/resource/reports/paying_for_better.transport.pdf
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 219 7vlxp www.lse.ac.uk/collections/pressAndInformationOffice/newsAndEvents/archives/2005/IDCardFinalReport.htm
 219 6x4nvu www.statoil.com/statoilcom/svg00990.nsf?opendatabase&artid=F5255D55E1E78319C1256FEF0044704B
 219 39g2wz www.dillinger.de/dh/referenzen/linepipe/01617/index.shtml.en
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 219 y7kg26 [www.politics.co.uk/issue-briefs/economy/taxation/tobacco-duty/tobacco-duty-\\$366602.htm](http://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
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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_JPA_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

Bibliography

- AITCHISON, E. (1996). Methane generation from UK landfill sites and its use as an energy resource. *Energy Conversion and Management*, 37(6/8):1111–1116. doi: doi:10.1016/0196-8904(95)00306-1. www.ingentaconnect.com/content/els/01968904/1996/00000037/00000006/art00306.
- AMOS, W. A. (2004). Updated cost analysis of photobiological hydrogen production from *Chlamydomonas reinhardtii* green algae – milestone completion report. www.nrel.gov/docs/fy04osti/35593.pdf.
- ANDERSON, K., BOWS, A., MANDER, S., SHACKLEY, S., AGNOLUCCI, P., and EKINS, P. (2006). Decarbonising modern societies: Integrated scenarios process and workshops. Technical Report 48, Tyndall Centre. www.tyndall.ac.uk/research/theme2/final_reports/t3.24.pdf.
- ARCHER, M. D. and BARBER, J. (2004). Photosynthesis and photoconversion. In M. D. Archer and J. Barber, editors, *Molecular to Global Photosynthesis*. World Scientific. ISBN 978-1-86094-256-3. www.worldscibooks.com/lifesci/p218.html.
- ASHWORTH, W. and PEGG, M. (1986). *The history of the British coal industry. Vol. 5, 1946–1982: the nationalized industry*. Clarendon, Oxford. ISBN 0198282958.
- ASPLUND, G. (2004). Sustainable energy systems with HVDC transmission. In *Power Engineering Society General Meeting*, volume 2, pages 2299–2303. IEEE. doi: 10.1109/PES.2004.1373296. www.trec-uk.org.uk/reports/HVDC_Gunnar_Asplund_ABB.pdf.
- ASSELBERGS, B., BOKHORST, J., HARMS, R., VAN HEMERT, J., VAN DER NOORT, L., TEN VELDEN, C., VERVUURT, R., WIJNEN, L., and VAN ZON, L. (2006). Size does matter – the possibilities of cultivating *Jatropha curcas* for biofuel production in Cambodia. environmental.scum.org/biofuel/jatropha/.
- BAER, P. and MASTRANDREA, M. (2006). High stakes: Designing emissions pathways to reduce the risk of dangerous climate change. www.ippr.org/publicationsandreports/.
- BAHRMAN, M. P. and JOHNSON, B. K. (2007). The ABCs of HVDC transmission technology. *IEEE Power and Energy Magazine*, 5(2).
- BAINES, J. A., NEWMAN, V. G., HANNA, I. W., DOUGLAS, T. H., CARLYLE, W. J., JONES, I. L., EATON, D. M., and ZERONIAN, G. (1983). Dinorwig pumped storage scheme. *Institution of Civil Engineers Proc. pt. 1*, 74:635–718.
- BAINES, J. A., NEWMAN, V. G., HANNA, I. W., DOUGLAS, T. H., CARLYLE, W. J., JONES, I. L., EATON, D. M., and ZERONIAN, G. (1986). Dinorwig pumped storage scheme. *Institution of Civil Engineers Proc. pt. 1*, 80:493–536.
- BAKER, C., WALBANCKE, J., and LEACH, P. (2006). Tidal lagoon power generation scheme in Swansea Bay. www.dti.gov.uk/files/file30617.pdf. A report on behalf of the Dept. of Trade and Industry and the Welsh Development Agency.
- BAYER CROP SCIENCE. (2003). Potential of GM winter oilseed rape to reduce the environmental impact of farming whilst improving farmer incomes. tinyurl.com/5j99df.
- BICKLEY, D. T. and RYRIE, S. C. (1982). A two-basin tidal power scheme for the Severn estuary. In *Conf. on new approaches to tidal power*.
- BINDER, M., FALTENBACHER, M., KENTZLER, M., and SCHUCKERT, M. (2006). Clean urban transport for Europe. deliverable D8 final report. www.fuel-cell-bus-club.com/.
- BLACK and VEATCH. (2005). The UK tidal stream resource and tidal stream technology. report prepared for the Carbon Trust Marine Energy Challenge. www.carbontrust.co.uk/technology/technologyaccelerator/tidalstream.htm.
- BLUNDEN, L. S. and BAHAJ, A. S. (2007). Tidal energy resource assessment for tidal stream generators. *Proc. IMechE*, 221 Part A: 137–146.
- BONAN, G. B. (2002). *Ecological Climatology: Concepts and Applications*. Cambridge Univ. Press. ISBN 9780521804769.
- BOYER, J. S. (1982). Plant productivity and environment. *Science*, 218 (4571):443–448. doi: 10.1126/science.218.4571.443.
- BRASLOW, A. L. (1999). *A history of suction-type laminar-flow control with emphasis on flight research*. Number 13 in Monographs in Aerospace History. NASA. www.nasa.gov/centers/dryden/pdf/88792main.Laminar.pdf.
- BROECKER, W. S. and KUNZIG, R. (2008). *Fixing Climate: What Past Climate Changes Reveal About the Current Threat—and How to Counter It*. Hill and Wang. ISBN 0809045028.
- BURNHAM, A., WANG, M., and WU, Y. (2007). Development and applications of GREET 2.7 — the transportation vehicle-cycle model. www.transportation.anl.gov/software/GREET/publications.html.
- CARBON TRUST. (2007). Micro-CHP accelerator – interim report. Technical Report CTC726. www.carbontrust.co.uk/publications/publicationdetail.htm?productid=CTC726.
- CARLSSON, L. (2002). “Classical” HVDC: still continuing to evolve. *Modern Power Systems*.
- CARTWRIGHT, D. E., EDDEN, A. C., SPENCER, R., and VASSIE, J. M. (1980). The tides of the northeast Atlantic Ocean. *Philos. Trans. R. Soc. Lond. Ser. A*, 298(1436):87–139.
- CATLING, D. T. (1966). Principles and practice of train performance applied to London Transport’s Victoria line. Paper 8, Convention on Guided Land Transport (London, 27–28 October 1966).
- CHARLIER, R. H. (2003a). Sustainable co-generation from the tides: A review. *Renewable and Sustainable Energy Reviews*, 7:187213.
- CHARLIER, R. H. (2003b). A “sleeper” awakes: tidal current power. *Renewable and Sustainable Energy Reviews*, 7:515529.
- CHARNEY, J. G., ARAKAWA, A., BAKER, D. J., BOLIN, B., DICKINSON, R. E., GOODY, R. M., LEITH, C. E., STOMMEL, H. M., and WUNSCH, C. I. (1979). Carbon dioxide and climate: A scientific assessment. www.nap.edu/catalog.php?record_id=12181.
- CHISHOLM, S. W., FALKOWSKI, P. G., and CULLEN, J. J. (2001). Discrediting ocean fertilisation. *Science*, 294(5541):309–310.

- CHITRAKAR, R., KANO, H., MIYAI, Y., and OOI, K. (2001). Recovery of lithium from seawater using manganese oxide adsorbent ($H_{1.6}Mn_{1.6}O_4$) derived from $Li_{1.6}Mn_{1.6}O_4$. *Ind. Eng. Chem. Res.*, 40(9):2054–2058. pubs.acs.org/cgi-bin/abstract.cgi/iecred/2001/40/109/abs/ie000911h.html.
- CHURCH, R. A., HALL, A., and KANEFSKY, J. (1986). *The history of the British coal industry. Vol. 3, 1830–1913: Victorian pre-eminence*. Clarendon, Oxford. ISBN 0198282842.
- COHEN, B. L. (1983). Breeder reactors: A renewable energy source. *American Journal of Physics*, 51(1):75–76. sustainablenuclear.org/PADs/pad11983cohen.pdf.
- COLEY, D. (2001). Emission factors for walking and cycling. www.centres.ex.ac.uk/cee/publications/reports/91.html.
- COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT. (2006). Managing our radioactive waste safely. www.corwm.org.uk/Pages/Current%20Publications/700%20-%20CoRWM%20July%202006%20Recommendations%20to%20Government.pdf.
- CUTE. (2006). Clean urban transport for Europe. detailed summary of achievements. www.fuel-cell-bus-club.com/.
- DAVID, J. and HERZOG, H. (2000). The cost of carbon capture. sequestration.mit.edu/pdf/David_and_Herzog.pdf. presented at the Fifth International Conf. on Greenhouse Gas Control Technologies, Cairns, Australia, August 13 - August 16 (2000).
- DAVIDSON, E. A. and JANSSENS, I. A. (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, 440:165–173. doi: doi:10.1038/nature04514. www.nature.com/nature/journal/v440/n7081/full/nature04514.html.
- DEFFEYES, K. S. and MACGREGOR, I. D. (1980). World uranium resources. *Scientific American*, pages 66–76.
- DENHOLM, P., KULCINSKI, G. L., and HOLLOWAY, T. (2005). Emissions and energy efficiency assessment of baseload wind energy systems. *Environ Sci Technol*, 39(6):1903–1911. ISSN 0013-936X. www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=15819254.
- DENISON, R. A. (1997). Life-cycle assessment for paper products. In E. Ellwood, J. Antle, G. Eyring, and P. Schulze, editors, *Wood in Our Future: The Role of Life-Cycle Analysis: Proc. a Symposium*. National Academy Press. ISBN 0309057450. books.nap.edu/openbook.php?record_id=5734.
- DENNIS, C. (2006). Solar energy: Radiation nation. *Nature*, 443:23–24. doi: 10.1038/443023a.
- DEPT. FOR TRANSPORT. (2007). Transport statistics Great Britain. www.dft.gov.uk/pgr/statistics/datatablespublications/tsgb/.
- DEPT. OF DEFENSE. (2008). More fight – less fuel. Report of the Defense Science Board Task Force on DoD Energy Strategy.
- DEPT. OF TRADE AND INDUSTRY. (2004). DTI Atlas of UK marine renewable energy resources. www.offshore-sea.org.uk/.
- DEPT. OF TRADE AND INDUSTRY. (2002a). Energy consumption in the United Kingdom. www.berr.gov.uk/files/file11250.pdf.
- DEPT. OF TRADE AND INDUSTRY. (2002b). Future offshore. www.berr.gov.uk/files/file22791.pdf.
- DEPT. OF TRADE AND INDUSTRY. (2007). Impact of banding the renewables obligation – costs of electricity production. www.berr.gov.uk/files/file39038.pdf.
- DESSLER, A. E. and PARSON, E. A. (2006). *The Science and Politics of Global Climate Change – A Guide to the Debate*. Cambridge Univ. Press, Cambridge. ISBN 9780521539418.
- DI PRAMPERO, P. E., CORTILI, G., MOGNONI, P., and SAIBENE, F. (1979). Equation of motion of a cyclist. *J. Appl. Physiology*, 47:201–206. jap.physiology.org/cgi/content/abstract/47/1/201.
- DIAMOND, J. (2004). *Collapse: How Societies Choose to Fail or Succeed*. Penguin.
- E4TECH. (2007). A review of the UK innovation system for low carbon road transport technologies. www.dft.gov.uk/pgr/scienceresearch/technology/1ctis/e4techlcpdf.
- ECKHARTT, D. (1995). Nuclear fuels for low-beta fusion reactors: Lithium resources revisited. *Journal of Fusion Energy*, 14(4):329–341. ISSN 0164-0313 (Print) 1572-9591 (Online). doi: 10.1007/BF02214511. www.springerlink.com/content/35470543rj8t2gk1/.
- EDDINGTON, R. (2006). Transport’s role in sustaining the UK’s productivity and competitiveness.
- EDEN, R. and BENDING, R. (1985). Gas/electricity competition in the UK. Technical Report 85/6, Cambridge Energy Research Group, Cambridge.
- ELLIOTT, D. L., WENDELL, L. L., and GOWER, G. L. (1991). An assessment of windy land area and wind energy potential in the contiguous United States. www.osti.gov/energycitations/servlets/purl/5252760-ccu0pk/.
- ENERGY FOR SUSTAINABLE DEVELOPMENT LTD. (2003). English partnerships sustainable energy review. www.englishpartnerships.co.uk.
- ERDINCER, A. U. and VESILIND, P. A. (1993). Energy recovery from mixed waste paper. *Waste Management & Research*, 11(6):507–513. doi: 10.1177/0734242X9301100605.
- ETHERIDGE, D., STEELE, L., LANGENFELDS, R., FRANCEY, R., BARNOLA, J.-M., and MORGAN, V. (1998). Historical CO₂ records from the Law Dome DE08, DE08-2, and DSS ice cores. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Dept. of Energy, Oak Ridge, Tenn, USA. cdiac.ornl.gov/trends/co2/lawdome.html.
- EUROPEAN COMMISSION. (2007). Concentrating solar power - from research to implementation. www.solarpaces.org/Library/library.htm.
- EVANS, D. G. (2007). Liquid transport biofuels – technology status report. www.nnfcc.co.uk/.
- EVANS, R. K. (2008). An abundance of lithium. www.worldlithium.com.
- FABER, T. E. (1995). *Fluid dynamics for physicists*. Cambridge Univ. Press, Cambridge.
- FAIMAN, D., RAVIV, D., and ROSENSTREICH, R. (2007). Using solar energy to arrest the increasing rate of fossil-fuel consumption: The southwestern states of the USA as case studies. *Energy Policy*, 35: 567576.

- FIES, B., PETERSON, T., and POWICKI, C. (2007). Solar photovoltaics – expanding electric generation options. mydocs.epri.com/docs/SEIG/1016279.Photovoltaic.White.Paper.1207.pdf.
- FISHER, K., WALLÉN, E., LAENEN, P. P., and COLLINS, M. (2006). Battery waste management life cycle assessment. www.defra.gov.uk/environment/waste/topics/batteries/pdf/erm-lcareport0610.pdf.
- FLATHER, R. A. (1976). A tidal model of the north-west European continental shelf. *Memoires Société Royale des Sciences de Liège*, 10 (6):141–164.
- FLINN, M. W. and STOKER, D. (1984). *The history of the British coal industry. Vol. 2, 1700–1830: the Industrial Revolution*. Clarendon, Oxford. ISBN 0198282834.
- FRANCIS, G., EDINGER, R., and BECKER, K. (2005). A concept for simultaneous wasteland reclamation, fuel production, and socio-economic development in degraded areas in India: Need, potential and perspectives of *Jatropha* plantations. *Natural Resources Forum*, 29(1):12–24. doi: 10.1111/j.1477-8947.2005.00109.x.
- FRANKLIN, J. (2007). Principles of cycle planning. www.cyclenetwork.org.uk/papers/071119principles.pdf.
- FREESTON, D. H. (1996). Direct uses of geothermal energy 1995. geoheat.oit.edu/bulletin/bull17-1/art1.pdf.
- GABRIELLI, G. and VON KÁRMÁN, T. (1950). What price speed? *Mechanical Engineering*, 72(10).
- GARRETT, C. and CUMMINS, P. (2005). The power potential of tidal currents in channels. *Proc. Royal Society A*, 461(2060):2563–2572. dx.doi.org/10.1098/rspa.2005.1494.
- GARRETT, C. and CUMMINS, P. (2007). The efficiency of a turbine in a tidal channel. *J Fluid Mech*, 588:243–251. journals.cambridge.org/production/action/cjoGetFulltext?fulltextid=1346064.
- GELLINGS, C. W. and PARMENTER, K. E. (2004). Energy efficiency in fertilizer production and use. In C. W. Gellings and K. Blok, editors, *Efficient Use and Conservation of Energy*, Encyclopedia of Life Support Systems. Eolss Publishers, Oxford, UK. www.eolss.net.
- GERMAN AEROSPACE CENTER (DLR) INSTITUTE OF TECHNICAL THERMODYNAMICS SECTION SYSTEMS ANALYSIS AND TECHNOLOGY ASSESSMENT. (2006). Concentrating solar power for the Mediterranean region. www.dlr.de/tt/med-csp. Study commissioned by Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany.
- GOODSTEIN, D. (2004). *Out of Gas*. W. W. Norton and Company, New York. ISBN 0393058573.
- GREEN, J. E. (2006). Civil aviation and the environment – the next frontier for the aerodynamicist. *Aeronautical Journal*, 110(1110): 469–486.
- GRUBB, M. and NEWBERY, D. (2008). Pricing carbon for electricity generation: national and international dimensions. In M. Grubb, T. Jamasb, and M. G. Pollitt, editors, *Delivering a Low Carbon Electricity System: Technologies, Economics and Policy*. Cambridge Univ. Press, Cambridge.
- GUMMER, J., GOLDSMITH, Z., PECK, J., EGGAR, T., HURD, N., MIRAJ, A., NORRIS, S., NORTHCOTE, B., OLIVER, T., STRONG, D., TWITCHEN, K., and WILKIE, K. (2007). Blueprint for a green economy. www.qualityoflifechallenge.com.
- HALKEMA, J. A. (2006). Wind energy: Facts and fiction. www.countryguardian.net/halkema-windenergyfactfiction.pdf.
- HAMMOND, G. and JONES, C. (2006). Inventory of carbon & energy (ICE). www.bath.ac.uk/mech-eng/sert/embodied/. version 1.5a Beta.
- HAMMONS, T. J. (1993). Tidal power. *Proc. IEEE*, 8(3):419–433.
- HANSEN, J., SATO, M., KHARECHA, P., RUSSELL, G., LEA, D., and SIDDALL, M. (2007). Climate change and trace gases. *Phil. Trans. Royal. Soc. A*, 365:1925–1954. doi: 10.1098/rsta.2007.2052. pubs.giss.nasa.gov/abstracts/2007/Hansen_et_al_2.html.
- HASTINGS, R. and WALL, M. (2006). *Sustainable Solar Housing: Strategies And Solutions*. Earthscan. ISBN 1844073254.
- HATCHER, J. (1993). *The History of the British Coal Industry: Towards the Age of Coal: Before 1700 Vol 1*. Clarendon Press.
- HEATON, E., VOIGT, T., and LONG, S. (2004). A quantitative review comparing the yields of two candidate C4 perennial biomass crops in relation to nitrogen, temperature, and water. *Biomass and Bioenergy*, 27:21–30.
- HELM, D., SMALE, R., and PHILLIPS, J. (2007). Too good to be true? The UK’s climate change record. www.dieterhelm.co.uk/publications/Carbon_record_2007.pdf.
- HELWEG-LARSEN, T. and BULL, J. (2007). Zero carbon Britain – an alternative energy strategy. zerocarbonbritain.com/.
- HERRING, J. (2004). Uranium and thorium resource assessment. In C. J. Cleveland, editor, *Encyclopedia of Energy*. Boston Univ., Boston, USA. ISBN 0-12-176480-X.
- HERZOG, H. (2003). Assessing the feasibility of capturing CO₂ from the air. web.mit.edu/coal/working_folder/pdfs/Air_Capture_Feasibility.pdf.
- HERZOG, H. (2001). What future for carbon capture and sequestration? *Environmental Science and Technology*, 35:148A–153A. sequestration.mit.edu/.
- HIRD, V., EMERSON, C., NOBLE, E., LONGFIELD, J., WILLIAMS, V., GOETZ, D., HOSKINS, R., PAXTON, A., and DUPEE, G. (1999). Still on the road to ruin? An assessment of the debate over the unnecessary transport of food, five years on from the food miles report.
- HODGSON, P. (1999). *Nuclear Power, Energy and the Environment*. Imperial College Press.
- HOPFIELD, J. J. and GOLLUB, J. (1978). Introduction to solar energy. www.inference.phy.cam.ac.uk/sustainable/solar/HopfieldGollub78/scan.html.
- HORIE, H., TANJO, Y., MIYAMOTO, T., and KOGA, Y. (1997). Development of a lithium-ion battery pack system for EV. *JSAE Review*, 18 (3):295–300.
- HPTCJ. (2007). Heat pumps: Long awaited way out of the global warming. www.hptcj.or.jp/about/e/contribution/index.html.
- INDERMUHLE, A., STOCKER, T., JOOS, F., FISCHER, H., SMITH, H., WAHLEN, M., DECK, B., MASTROIANNI, D., TSCHUMI, J., BLUNIER, T., MEYER, R., and STAUFFER, B. (1999). Holocene carbon-cycle dynamics based on CO₂ trapped in ice at Taylor Dome, Antarctica. *Nature*, 398:121–126.

- INTERNATIONAL ENERGY AGENCY. (2001). Things that go blip in the night – standby power and how to limit it. www.iea.org/textbase/nppdf/free/2000/blipinthenight01.pdf.
- JACKSON, P. and KERSHAW, S. (1996). Reducing long term methane emissions resulting from coal mining. *Energy Conversion and Management*, 37(6-8):801–806. doi: 10.1016/0196-8904(95)00259-6.
- JEVONS, W. S. (1866). *The Coal Question; An Inquiry concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-mines*. Macmillan and Co., London, second edition. o11.libertyfund.org/.
- JONES, I. S. F. (2008). The production of additional marine protein by nitrogen nourishment. www.oceannourishment.com/files/Jc08.pdf.
- JONES, P. M. S. (1984). Statistics and nuclear energy. *The Statistician*, 33(1):91–102. www.jstor.org/pss/2987717.
- JUDD, B., HARRISON, D. P., and JONES, I. S. F. (2008). Engineering ocean nourishment. In *World Congress on Engineering WCE 2008*, pages 1315–1319. IAENG. ISBN 978-988-98671-9-5.
- JUNIPER, T. (2007). *How Many Lightbulbs does it take To Change a Planet?* Quercus, London.
- KAMMEN, D. M. and HASSENZAHL, D. M. (1999). *Should We Risk It? Exploring Environmental, Health, and Technological Problem Solving*. Princeton Univ. Press.
- KANEKO, T., SHIMADA, M., KUJIRAOKA, S., and KOJIMA, T. (2004). Easy maintenance and environmentally-friendly train traction system. *Hitachi Review*, 53(1):15–19. www.hitachi.com/ICSFiles/afiefieldfile/2004/05/25/r2004.01.103.pdf.
- KEELING, C. and WHORE, T. (2005). Atmospheric CO₂ records from sites in the SIO air sampling network. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Dept. of Energy, Oak Ridge, Tenn., USA.
- KEITH, D. W., HA-DUONG, M., and STOLAROFF, J. K. (2005). Climate strategy with CO₂ capture from the air. *Climatic Change*. doi: 10.1007/s10584-005-9026-x. www.ucalgary.ca/~keith/papers/51.Keith.2005.ClimateStratWithAirCapture.e.pdf.
- KING, J. (2007). The King review of low-carbon cars. Part I: the potential for CO₂ reduction. hm-treasury.gov.uk/king.
- KING, J. (2008). The King review of low-carbon cars. Part II: recommendations for action. hm-treasury.gov.uk/king.
- KOOMEY, J. G. (2007). Estimating total power consumption by servers in the US and the world. blogs.business2.com/greenwombat/files/serverpowerusecomplete-v3.pdf.
- KOWALIK, Z. (2004). Tide distribution and tapping into tidal energy. *Oceanologia*, 46(3):291–331.
- KUEHR, R. (2003). *Computers and the Environment: Understanding and Managing their Impacts (Eco-Efficiency in Industry and Science)*. Springer. ISBN 1402016808.
- LACKNER, K. S., GRIMES, P., and ZIOCK, H.-J. (2001). Capturing carbon dioxide from air. www.net1.doe.gov/publications/proceedings/01/carbon_seq/7b1.pdf. Presented at First National Conf. on Carbon Sequestration, Washington DC.
- LAWSON, B. (1996). Building materials, energy and the environment: Towards ecologically sustainable development.
- LAYZELL, D. B., STEPHEN, J., and WOOD, S. M. (2006). Exploring the potential for biomass power in Ontario. www.biocap.ca/files/Ont.bioenergy_OPA_Feb23_final.pdf.
- LE QUÉRÉ, C., RÖDENBECK, C., BUITENHUIS, E., CONWAY, T. J., LANGENFELDS, R., GOMEZ, A., LABUSCHAGNE, C., RAMONET, M., NAKAZAWA, T., METZL, N., GILLET, N., and HEIMANN, M. (2007). Saturation of the southern ocean CO₂ sink due to recent climate change. *Science*, 316:1735–1738. doi: 10.1126/science.1136188. lmgacweb.env.uea.ac.uk/e415/publications.html.
- LEMOFOUET-GATSI, S. (2006). *Investigation and optimisation of hybrid electricity storage systems based on compressed air and supercapacitors*. PhD thesis, EPFL. library.epfl.ch/theses/?nr=3628.
- LEMOFOUET-GATSI, S. and RUFER, A. (2005). Hybrid energy systems based on compressed air and supercapacitors with maximum efficiency point tracking. www.epfl.ch/publications/lemofouet_rufer_epe_05.pdf.
- LOMBORG, B. (2001). *The skeptical environmentalist: measuring the real state of the world*. Cambridge Univ. Press, Cambridge. ISBN 0-521-80447-7.
- MABEE, W. E., SADDLER, J. N., NIELSEN, C., HENRIK, L., and STEEN JENSEN, E. (2006). Renewable-based fuels for transport. www.risoe.dk/rispubl/Energy-report5/ris-r-1557.49-52.pdf. Riso Energy Report 5.
- MACDONALD, J. M. (2008). The economic organization of US broiler production. www.ers.usda.gov/Publications/EIB38/EIB38.pdf. Economic Information Bulletin No. 38. Economic Research Service, US Dept. of Agriculture.
- MACDONALD, P., STEDMAN, A., and SYMONS, G. (1992). The UK geothermal hot dry rock R&D programme. In *Seventeenth Workshop on Geothermal Reservoir Engineering*.
- MACKAY, D. J. C. (2007a). Enhancing electrical supply by pumped storage in tidal lagoons. www.inference.phy.cam.ac.uk/mackay/abstracts/Lagoons.html.
- MACKAY, D. J. C. (2007b). Under-estimation of the UK tidal resource. www.inference.phy.cam.ac.uk/mackay/abstracts/TideEstimate.html.
- MACLEAY, I., HARRIS, K., and MICHAELS, C. (2007). Digest of United Kingdom energy statistics 2007. www.berr.gov.uk.
- MALANIMA, P. (2006). Energy crisis and growth 1650–1850: the European deviation in a comparative perspective. *Journal of Global History*, 1:101–121. doi: 10.1017/S1740022806000064.
- MARLAND, G., BODEN, T., and ANDRES, R. J. (2007). Global, regional, and national CO₂ emissions. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Dept. of Energy, Oak Ridge, Tenn., USA. cdiac.ornl.gov/trends/emis/tre_glob.htm.
- MASSACHUSETTS INSTITUTE OF TECHNOLOGY. (2006). The future of geothermal energy. geothermal.inel.gov/publications/future_of_geothermal_energy.pdf.
- MCBRIDE, J. P., MOORE, R. E., WITHERSPOON, J. P., and BLANCO, R. E. (1978). Radiological impact of airborne effluents of coal and nu-

- clear plants. *Science*, 202(4372):1045–1050. doi: 10.1126/science.202.4372.1045.
- MEADOWS, M. (1996). Estimating landfill methane emissions. *Energy Conversion and Management*, 37(6-8):1099–1104. doi: 10.1016/0196-8904(95)00304-5.
- B. Metz, O. Davidson, H. de Coninck, M. Loos, and L. Meyer, editors. (2005). *Special Report on Carbon Dioxide Capture and Storage*. Cambridge Univ. Press, Cambridge. ISBN 978-0-521-68551-1. www.ipcc.ch/ipccreports/srccs.htm.
- MILLS, D. R. and LIÈVRE, P. L. (2004). Competitive solar electricity. www.ausra.com/pdfs/Paper_CompetitiveSolarElectricity.pdf.
- MILLS, D. R. and MORGAN, R. G. (2008). Solar thermal electricity as the primary replacement for coal and oil in US generation and transportation. www.ausra.com/technology/reports.html.
- MILLS, D. R. and MORRISON, G. L. (2000). Compact Linear Fresnel Reflector solar thermal powerplants. *Solar Energy*, 68(3):263–283. doi: 10.1016/S0038-092X(99)00068-7.
- MILLS, D. R., LE LIÈVRE, P., and MORRISON, G. L. (2004). First results from Compact Linear Fresnel Reflector installation. solarheatpower.veritel.com.au/MILLS_CLFR_ANZSES_FINAL.pdf.
- MINDL, P. (2003). Hybrid drive super-capacitor energy storage calculation. www3.fs.cvut.cz/web/fileadmin/documents/12241-BOZEK/publikace/2003/Supcap6.EDPE.pdf.
- MOLLISON, D. (1986). Wave climate and the wave power resource. In D. Evans and A. de O. Falcao, editors, *Hydrodynamic of Ocean Wave-Energy Utilization*, pages 133–156, Berlin. Springer. www.ma.hw.ac.uk/~denis/wave.html.
- MOLLISON, D. (1991). The UK wave power resource. In *Wave Energy (Institution of Mechanical Engineers – Seminar)*, pages 1–6. John Wiley & Sons. www.ma.hw.ac.uk/~denis/wave.html.
- MOLLISON, D., BUNEMAN, O. P., and SALTER, S. H. (1976). Wave power availability in the NE Atlantic. *Nature*, 263(5574):223–226. www.ma.hw.ac.uk/~denis/wave.html.
- MONTEITH, J. L. (1977). Climate and the efficiency of crop production in Britain. *Philos. Trans. R. Soc. London*, 281:277–294.
- NATIONAL BUREAU OF ECONOMIC RESEARCH. (2001). NBER macro-history database. www.nber.org/databases/macroeconomy/contents/.
- NEFTEL, A., FRIEDLI, H., MOOR, E., LTSCHER, H., OESCHGER, H., SIEGENTHALER, U., and STAUFFER, B. (1994). Historical CO₂ record from the Siple station ice core. In *Trends: A Compendium of Data on Global Change*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Dept. of Energy, Oak Ridge, Tenn., USA. cdiac.ornl.gov/trends/co2/siple.htm.
- NETHERLANDS ENVIRONMENTAL ASSESSMENT AGENCY. (2006). History database of the global environment. www.mnp.nl/hyde/.
- NICKOL, C. L. (2008). Silent Aircraft Initiative concept risk assessment. ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080012497_2008011089.pdf.
- NORRSTRÖM, H. (1980). Low waste technology in pulp and paper industries. *Pure & Appl. Chem.*, 52:1999–2004. www.iupac.org/publications/pac/1980/pdf/5208x1999.pdf.
- NUTTALL, W. J. (2004). *Nuclear Renaissance*. Institute of Physics Publishing.
- OECD NUCLEAR ENERGY AGENCY. (2006). *Forty Years of Uranium Resources, Production and Demand in perspective*. OECD Publishing. ISBN 9264028064. books.google.com/books?id=HIT1o985uKYC.
- ONGENA, J. and VAN OOST, G. (2006). Energy for future centuries. Will fusion be an inexhaustible, safe and clean energy source? www.fusie-energie.nl/artikelen/ongena.pdf.
- OSWALD, J., RAINE, M., and ASHRAF-BALL, H. (2008). Will British weather provide reliable electricity? *Energy Policy*, in press. doi: 10.1016/j.enpol.2008.04.03.
- PRICE, R. and BLAISE, J. (2002). Nuclear fuel resources: Enough to last? www.ingentaconnect.com/content/oecd/16059581/2002/00000020/00000002/6802021e.
- PUTT, R. (2007). Algae as a biodiesel feedstock: A feasibility assessment. www.eere.energy.gov/afdc/pdfs/algae.pdf.
- QUAYLE, R. G. and CHANGERY, M. J. (1981). Estimates of coastal deep-water wave energy potential for the world. *Oceans*, 13:903–907. ieeexplore.ieee.org/iel6/8271/25889/01151590.pdf.
- RICE, T. and OWEN, P. (1999). *Decommissioning the Brent Spar*. Taylor and Francis.
- RICHARDS, B. S. and WATT, M. E. (2007). Permanently dispelling a myth of photovoltaics via the adoption of a new net energy indicator. *Renewable and Sustainable Energy Reviews*, 11(1):162172. www.sciencedirect.com/science/journal/13640321.
- RICHARDS, H. G., PARKER, R. H., GREEN, A. S. P., JONES, R. H., NICHOLLS, J. D. M., NICOL, D. A. C., RANDALL, M. M., RICHARDS, S., STEWART, R. C., and WILLIS-RICHARDS, J. (1994). The performance and characteristics of the experimental hot dry rock geothermal reservoir at Rosemanowes, Cornwall (1985-1988). *Geothermics*, 23(2):73–109. ISSN 0375-6505.
- RIDLEY, T. M. and CATLING, D. T. (1982). The energy implications of the design of mass transit railways. Presented at Tunnelling '82 (Third International Symposium), Brighton.
- ROGNER, H.-H. (2000). Energy resources. In *World Energy Assessment – Energy and the challenge of sustainability*, chapter 5. UNDP, New York, USA. www.undp.org/energy/activities/wea/draft-start.html.
- ROSS, A. (2008). The Loch Sloy hydro-electric scheme 1950. www.arrocharheritage.com/LochSloyHydroElectricScheme.htm.
- ROYAL COMMISSION ON ENVIRONMENTAL POLLUTION. (2004). Biomass as a renewable energy source. www.rcep.org.uk.
- ROYAL SOCIETY WORKING GROUP ON BIOFUELS. (2008). Sustainable biofuels: prospects and challenges. royalsociety.org. Policy document 01/08.
- RUBBIA, C., RUBIO, J., BUONO, S., CARMINATI, F., FIÉTIER, N., GALVEZ, J., GELÈS, C., KADI, Y., KLAPISCH, R., MANDRILLON, P., REVOL, J., and ROCHE, C. (1995). Conceptual design of a fast neutron operated high power energy amplifier. Technical Report CERN/AT/95-44 (ET), European Organization for Nuclear Research. doc.cern.ch/archive/electronic/other/generic/public/cer-0210391.pdf.

- RUDDLELL, A. (2003). Investigation on storage technologies for intermittent renewable energies: Evaluation and recommended r&d strategy. www.itpower.co.uk/investire/pdfs/flywheelrep.pdf.
- RYDH, C. J. and KARLSTRÖM, M. (2002). Life cycle inventory of recycling portable nickel-cadmium batteries. *Resources, Conservation and Recycling*, 34:289–309. homepage.te.hik.se/personal/tryca/battery/abstracts.htm.
- SALTER, S. H. (2005). Possible under-estimation of the UK tidal resource. www.berr.gov.uk/files/file31313.pdf. Submission for DTI Energy Review.
- SHELLNHUBER, H. J., CRAMER, W., NAKICENOVIC, N., WIGLEY, T., and YOHE, G. (2006). *Avoiding Dangerous Climate Change*. Cambridge Univ. Press. www.defra.gov.uk/environment/climatechange/internat/pdf/avoid-dangercc.pdf.
- SCHIERMEIER, Q., TOLLEFSON, J., SCULLY, T., WITZE, A., and MORTON, O. (2008). Energy alternatives: Electricity without carbon. *Nature*, 454:816–823. doi: 10.1038/454816a.
- SCHLAICH, J., BERGERMANN, R., W, S., and G, W. (2005). Design of commercial solar updraft tower systems – utilization of solar induced convective flows for power generation. *Journal of Solar Energy Engineering*, 127(1):117–124. doi: 10.1115/1.1823493. www.sbp.de/de/html/contact/download/TheSolarUpdraft.pdf.
- SCHLAICH J, S. W. *Solar Chimneys*. Academic Press, London, 3rd edition, (2001). ISBN 0-12-227410-5. www.solarmillennium.de/pdf/SolarCh.pdf.
- SCHMER, M. R., VOGEL, K. P., MITCHELL, R. B., and PERRIN, R. K. (2008). Net energy of cellulosic ethanol from switchgrass. *PNAS*, 105(2):464–469. doi: 10.1073/pnas.0704767105. www.pnas.org/cgi/content/full/105/2/464.
- SCHUILING, R. and KRIJGSMAN, P. (2006). Enhanced weathering; an effective and cheap tool to sequester CO₂. *Climatic Change*, 74(1-3): 349–354.
- S. I. Schwartz, editor. (1998). *Atomic Audit: Costs and Consequences of US Nuclear Weapons Since 1940*. Brookings Institution Press, Washington, D.C. www.brook.edu/fp/projects/nucwcost/schwartz.htm.
- SEKO, N., KATAKAI, A., HASEGAWA, S., TAMADA, M., KASAI, N., TAKEDA, H., SUGO, T., and SAITO, K. (2003). Aquaculture of uranium in seawater by a fabric-adsorbent submerged system. *Nuclear Technology*, 144(2):274–278.
- SHAPOURI, H., DUFFIELD, J. A., and GRABOSKI, M. S. (1995). Estimating the net energy balance of corn ethanol. www.ethanol-gec.org/corn_eth.htm. United States Dept. of Agriculture Agricultural Economic Report Number 721.
- SHARMAN, H. (2005). Why wind power works for Denmark. *Proc. ICE Civil Engineering*, 158:6672. incoteco.com/upload/CIEN.158.2.66.pdf.
- SHAW, T. L. and WATSON, M. J. (2003a). The effects of pumping on the energy potential of a tidal power barrage. *Engineering Sustainability*, 156(2):111–117. ISSN 1478-4637. doi: 10.1680/ensu.156.2.111.37018.
- SHAW, T. L. and WATSON, M. J. (2006). Flexible power generation from a Severn barrage. www.dti.gov.uk/files/file31332.pdf.
- SHAW, T. L. and WATSON, M. J. (2003b). Flexible power generation from the tides. *Engineering Sustainability*, 156(2):119–123. ISSN 1478-4629.
- SHEPHERD, D. W. (2003). *Energy Studies*. Imperial College Press.
- SHOCKLEY, W. and QUEISSER, H. J. (1961). Detailed balance limit of efficiency of $p-n$ junction solar cells. *Journal of Applied Physics*, 32(3):510–519.
- SHYY, W., BERG, M., and LJUNGQVIST, D. (1999). Flapping and flexible wings for biological and micro air vehicles. *Progress in Aerospace Sciences*, 35(5):455–505.
- SIEGENTHALER, U., MONNIN, E., KAWAMURA, K., SPAHNI, R., SCHWANDER, J., STAUFFER, B., STOCKER, T., BARNOLA, J.-M., and FISCHER, H. (2005). Supporting evidence from the EPICA Dronning Maud Land ice core for atmospheric CO₂ changes during the past millennium. *Tellus B*, 57(1):51–57. doi: 10.1111/j.1600-0889.2005.00131.x. <ftp://ftp.ncdc.noaa.gov/pub/data/paleo/icecore/antarctica/maud/edml-co2-2005.xls>.
- SIMS, R., SCHOCK, R., ADEGBULULGBE, A., FENHANN, J., KONSTANTINAVICIUTE, I., MOOMAW, W., NIMIR, H., SCHLAMADINGER, B., TORRES-MARTNEZ, J., TURNER, C., UCHIYAMA, Y., VUORI, S., WAMUKONYA, N., and ZHANG, X. (2007). Energy supply. In B. Metz, O. Davidson, P. Bosch, R. Dave, and L. Meyer, editors, *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge Univ. Press, Cambridge. www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter4.pdf.
- SINDEN, G. (2005). Variability of UK marine resources. Technical report, Oxford. www.carbontrust.co.uk/NR/rdonlyres/EC293061-611D-4BC8-A75C-9F84138184D3/0/variability_uk_marine_energy_resources.pdf.
- SLEATH, J. F. A. (1984). *Sea bed mechanics*. Wiley, New York. ISBN 047189091X.
- SOCOLOW, R. (2006). Stabilization wedges: An elaboration of the concept. In H. J. Schellnhuber, W. Cramer, N. Nakicenovic, T. Wigley, and G. Yohe, editors, *Avoiding Dangerous Climate Change*. Cambridge Univ. Press.
- STEINBERG, M. and DANG, V. (1975). Preliminary design and analysis of a process for the extraction of lithium from seawater. Technical Report 20535-R, Brookhaven National Lab., Upton, N.Y. (USA). www.osti.gov/energycitations/product.biblio.jsp?osti_id=7351225. Presented at Symposium on United States lithium resources and requirements by the year 2000; 22 Jan 1976; Lake-wood, CO, USA.
- STERN, N. (2007). *The Economics of Climate Change*. Cambridge Univ. Press, Cambridge.
- SUBCOMMITTEE ON POULTRY NUTRITION, NATIONAL RESEARCH COUNCIL. (1994). *Nutrient Requirements of Poultry*. National Academy Press, Washington, ninth revised edition. www.nap.edu/openbook.php?isbn=0309048923.
- SUPPLE, B. (1987). *The history of the British coal industry. Vol. 4, 1913–1946: the political economy of decline*. Clarendon, Oxford. ISBN 019828294X.

- TAYLOR, G. I. (1920). Tidal friction in the Irish Sea. *R. Soc. Lond. Ser. A*, 220:1–33. doi: 10.1098/rsta.1920.0001.
- TAYLOR, G. K. (2002a). Are you missing the boat? the ekranoplan in the 21st century – its possibilities and limitations. www.hypercraft-associates.com/areyoumissingtheboat2002.pdf. Presented at the 18th Fast Ferry Conf., Nice, France.
- TAYLOR, S. J. (2002b). The Severn barrage – definition study for a new appraisal of the project. www.dti.gov.uk/files/file15363.pdf. ETSU REPORT NO. T/09/00212/00/REP.
- TENNEKES, H. (1997). *The Simple Science of Flight*. MIT Press.
- THAKUR, P. C., LITTLE, H. G., and KARIS, W. G. (1996). Global coalbed methane recovery and use. *Energy Conversion and Management*, 37(6/8):789–794.
- THE EARTHWORKS GROUP. (1989). *50 Simple things you can do to save the earth*. The Earthworks Press, Berkeley, California. ISBN 0-929634-06-3.
- TRELOAR, G. J., LOVE, P. E. D., and CRAWFORD, R. H. (2004). Hybrid life-cycle inventory for road construction and use. *J. Constr. Engrg. and Mgmt.*, 130(1):43–49.
- TRIEB, F. and KNIES, G. (2004). A renewable energy and development partnership EU-ME-NA for large scale solar thermal power and desalination in the Middle East and in North Africa. www.gezen.nl/wordpress/wp-content/uploads/2006/09/sanaa-paper-and-annex.15-04-2004.pdf.
- TSURUTA, T. (2005). Removal and recovery of lithium using various microorganisms. *Journal of Bioscience and Bioengineering*, 100(5):562–566. www.jstage.jst.go.jp/article/jbb/100/5/100_562/article.
- TURKENBURG, W. C. (2000). Renewable energy technologies. In *World Energy Assessment – Energy and the challenge of sustainability*, chapter 7. UNDP, New York, USA. www.undp.org/energy/activities/wea/draft-start.html.
- UCUNCU, A. (1993). Energy recovery from mixed paper waste. Technical report, NC, USA. www.p2pays.org/ref/11/10059.pdf.
- VAN DEN BERG, G. (2004). Effects of the wind profile at night on wind turbine sound. *Journal of Sound and Vibration*, 277:955–970. www.nowap.co.uk/docs/windnoise.pdf.
- VAN VOORTHUYSEN, E. D. M. (2008). Two scenarios for a solar world economy. *Int. J. Global Environmental Issues*, 8(3):233247.
- VENTOUR, L. (2008). The food we waste. news.bbc.co.uk/1/shared/bsp/hi/pdfs/foodwewaste_fullreport08_05_08.pdf.
- WARWICK HRI. (2007). Direct energy use in agriculture: opportunities for reducing fossil fuel inputs. www2.warwick.ac.uk/fac/sci/whri/research/climatechange/energy/direct_energy_use_in_agriculture.pdf.
- WATER UK. (2006). Towards sustainability 2005–2006. www.water.org.uk/home/policy/reports/sustainability/indicators-2005-06/towards-sustainability-2005-2006.pdf.
- WATSON, J., HERTIN, J., RANDALL, T., and GOUGH, C. (2002). Renewable energy and combined heat and power resources in the UK. Technical report. www.tyndall.ac.uk/publications/working-papers/wp22.pdf. Working Paper 22.
- WAVEGEN. (2002). Islay Limpet project monitoring – final report. www.wavegen.co.uk/pdf/art.1707.pdf.
- WEBER, C. L. and MATTHEWS, H. S. (2008). Food-miles and the relative climate impacts of food choices in the United States. *Environ. Sci. Technol.*, 42(10):3508–3513. doi: 10.1021/es702969f.
- WEIGHTMAN, M. (2007). Report of the investigation into the leak of dissolver product liquor at the Thermal Oxide Reprocessing Plant (THORP), Sellafield, notified to HSE on 20 April 2005. www.hse.gov.uk/nuclear/thorpreport.pdf.
- WIEDMANN, T., WOOD, R., LENZEN, M., MINX, J., GUAN, D., and BARRATT, J. (2008). Development of an embedded carbon emissions indicator producing a time series of input-output tables and embedded carbon dioxide emissions for the UK by using a MRIO data optimisation system. randd.defra.gov.uk/Document.aspx?Document=EV02033_7331_FRP.pdf.
- WILLIAMS, D. and BAVERSTOCK, K. (2006). Chernobyl and the future: Too soon for a final diagnosis. *Nature*, 440:993–994. doi: 10.1038/440993a.
- WILLIAMS, E. (2004). Energy intensity of computer manufacturing: hybrid assessment combining process and economic input-output methods. *Environ Sci Technol*, 38(22):6166–6174. ISSN 0013-936X. [url{www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=15573621}](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=15573621).
- WILLIAMS, R. H. (2000). Advanced energy supply technologies. In *World Energy Assessment – Energy and the challenge of sustainability*, chapter 8. UNDP, New York, USA. www.undp.org/energy/activities/wea/draft-start.html.
- WILSON, E. M. and BALLS, M. (1990). Tidal power generation. In P. Novak, editor, *Developments in Hydraulic Engineering*, chapter 2. Taylor & Francis. ISBN 185166095X.
- WOOD, B. (1985). Economic district heating from existing turbines. *Institution of Civil Engineers Proc. pt. 1*, 77:27–48.
- YAROS, B. (1997). Life-cycle thinking for wood and paper products. In E. Ellwood, J. Antle, G. Eyring, and P. Schulze, editors, *Wood in Our Future: The Role of Life-Cycle Analysis: Proc. a Symposium*.
- ZALESKI, C. P. (2005). The future of nuclear power in France, the EU and the world for the next quarter-century. www.npec-web.org/Essays/Essay050120Zalenski-FutureofNuclearPower.pdf. tinyurl.com/32louu.
- ZHU, X.-G., LONG, S. P., and ORT, D. R. (2008). What is the maximum efficiency with which photosynthesis can convert solar energy into biomass? *Current Opinion in Biotechnology*, 19:153159.

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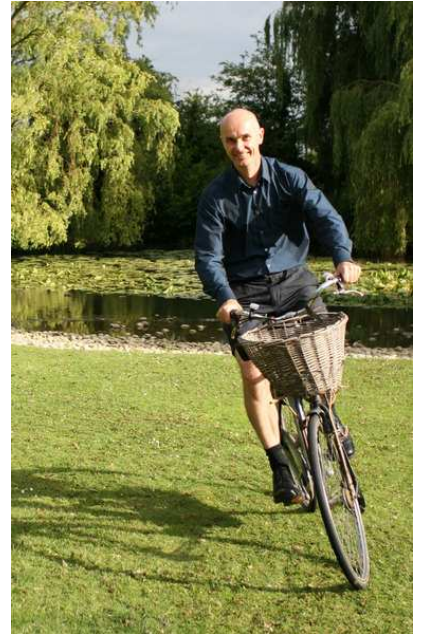
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Sustainable Energy – without the hot air

David JC MacKay

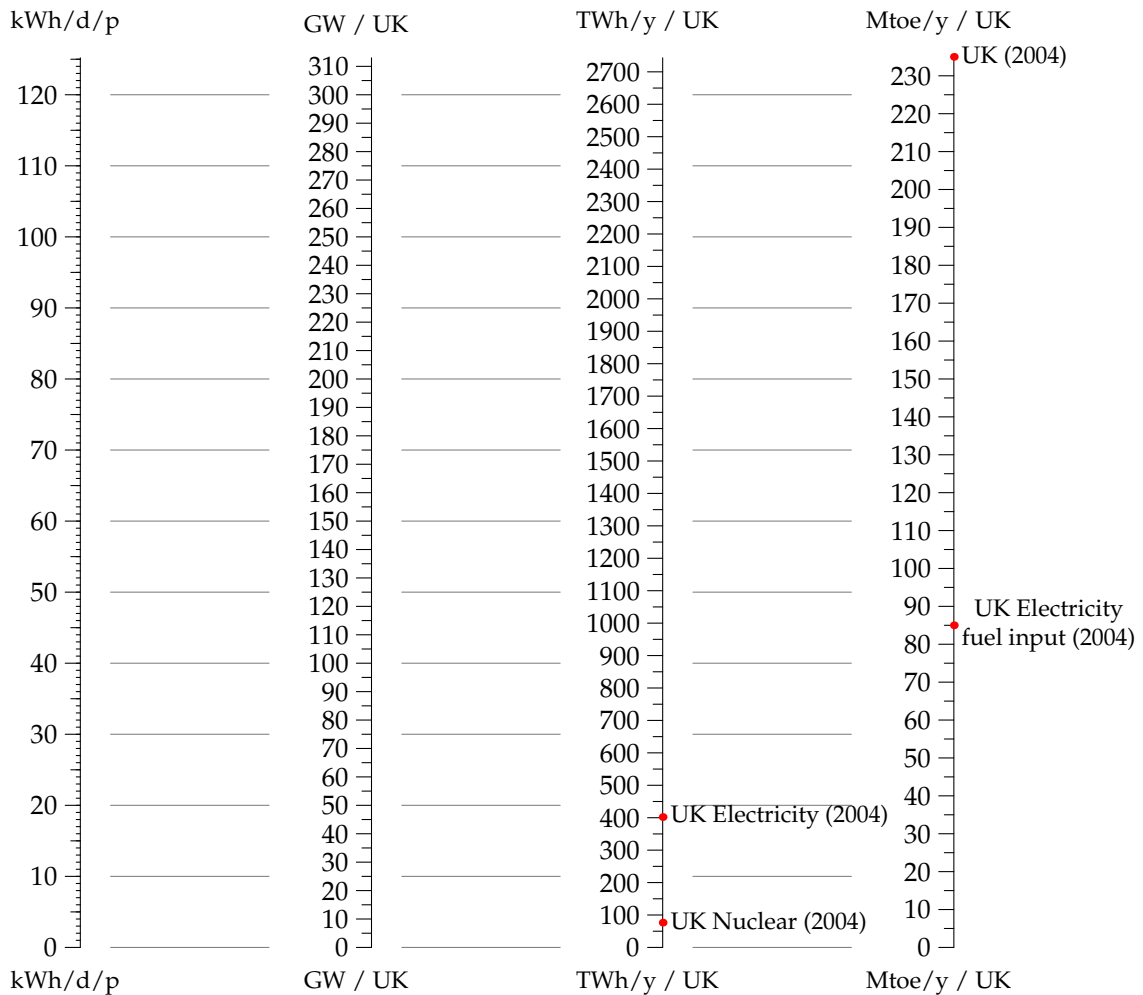
About the author

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 $\frac{1}{24}$ 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.

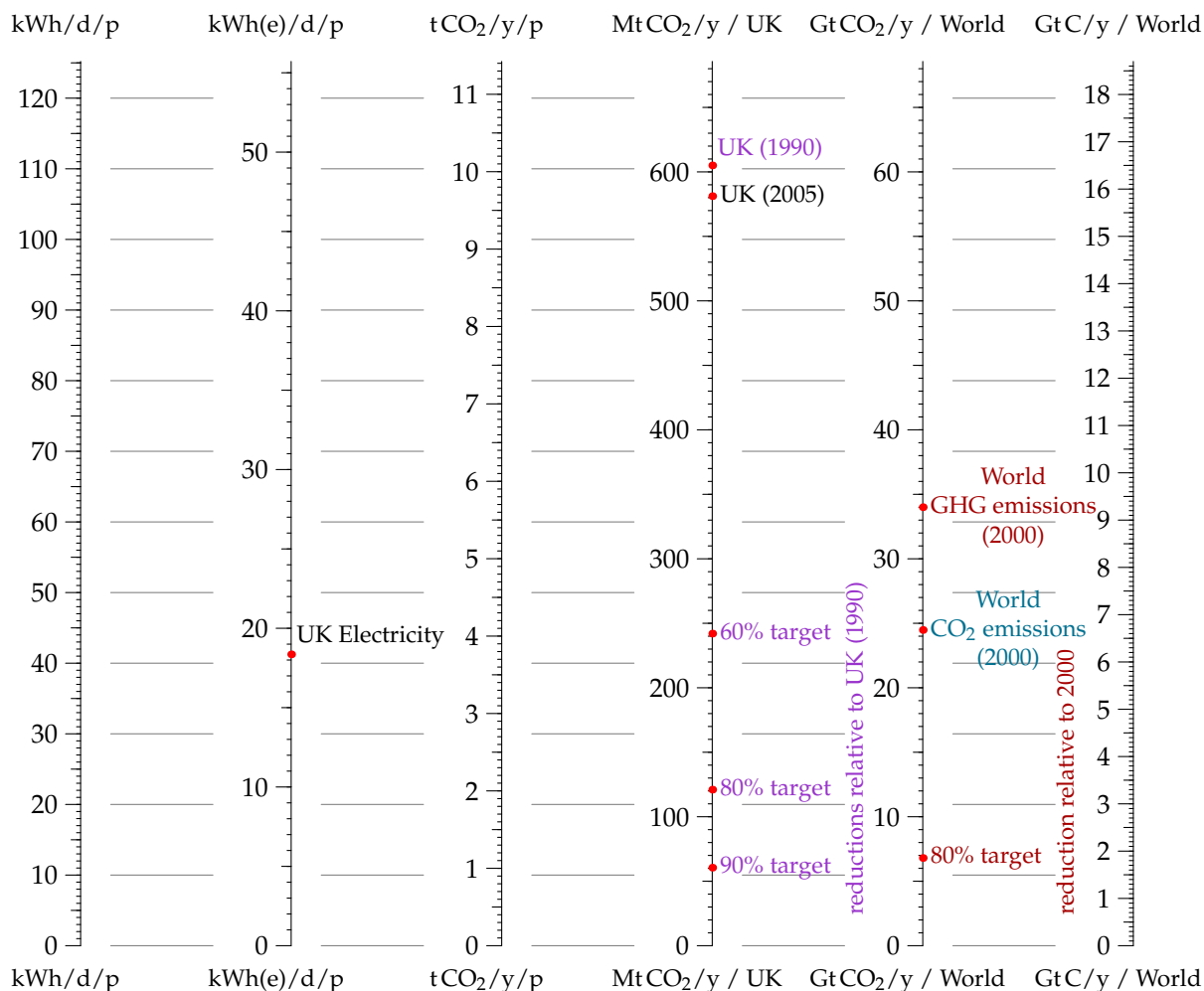
gigawatts (GW).

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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PO Box 145
Cambridge
CB4 1GQ
England

E-mail: *inquiries@uit.co.uk*

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