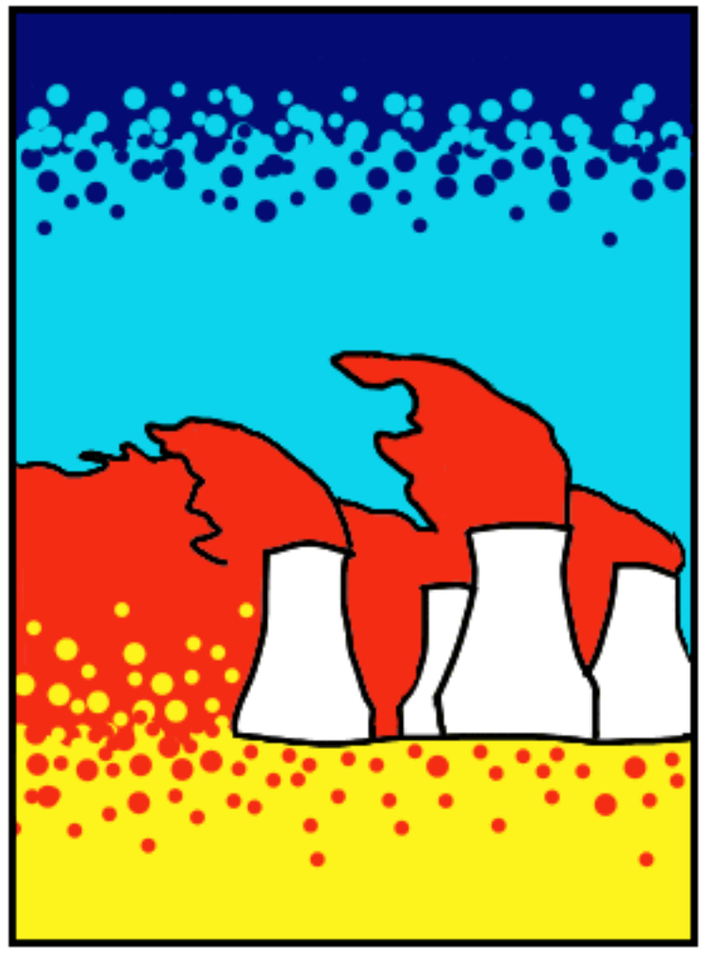
Sustainable Energy

- without the hot air



David MacKay FRS

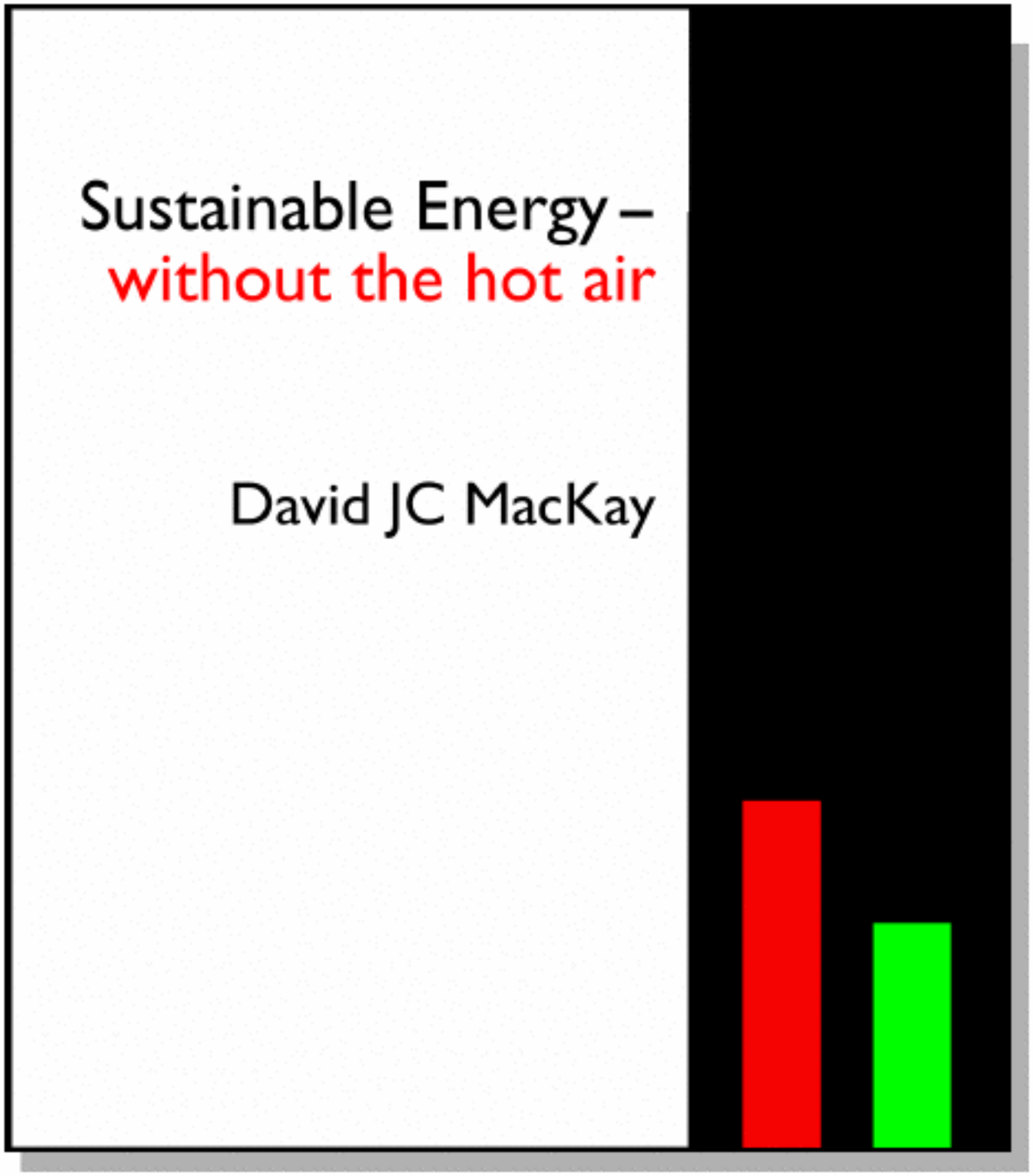
Cavendish Laboratory
University of Cambridge

www.withouthotair.com

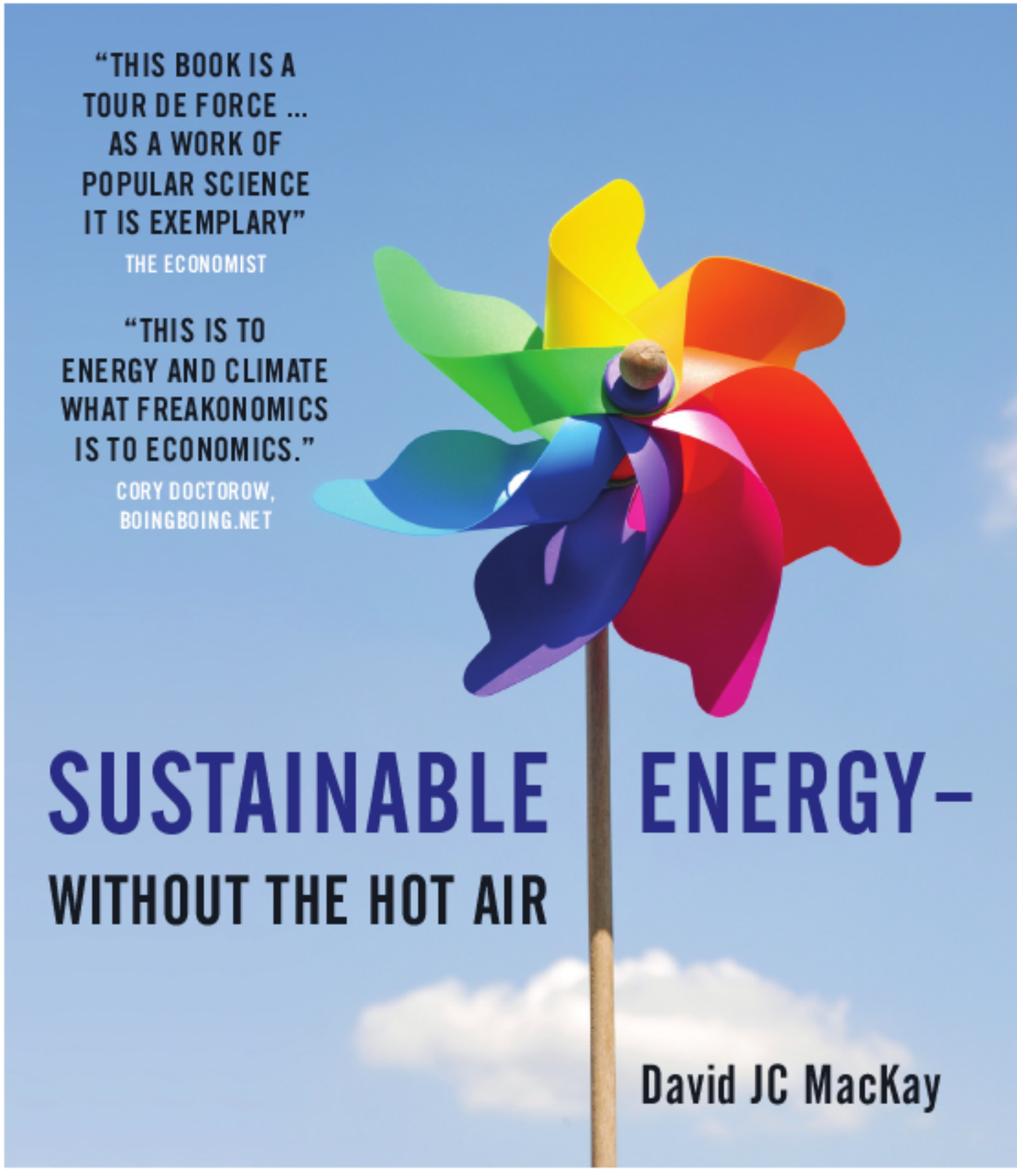
DEPARTMENT OF ENERGY & CLIMATE CHANGE

Sustainable Energy – without the hot air

David JC MacKay



Publisher: UIT Cambridge



£20

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over 2 tons per person of stuff every year, of which about 1.3 tons per person are processed and manufactured stuff like vehicles, machinery, white goods, and electrical and electronic equipment. That's about 4 kg per day per person of processed stuff. Such goods are mainly made of materials whose production required at least 10 kWh of energy per kg of stuff. I thus estimate that this pile of cars, fridges, microwaves, computers, photocopiers and televisions has an embodied energy of at least 40 kWh per day per person.

To summarize all these forms of

stuff-transport, I will put on

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Sustainable Energy – without the hot air

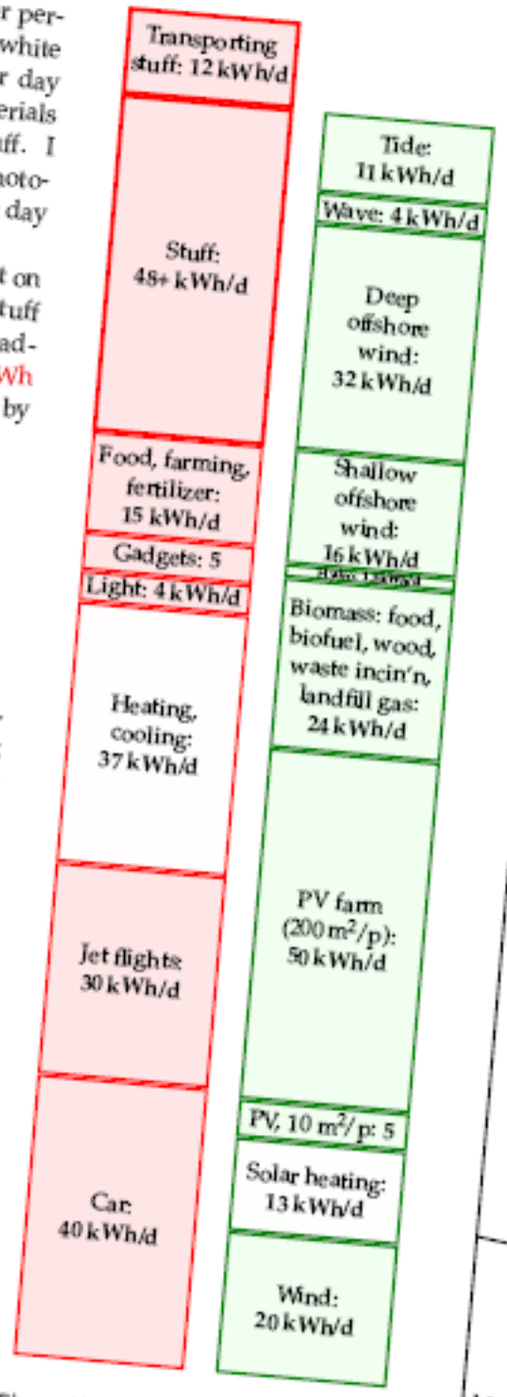

Figure 15.11. Making our stuff costs at least 48 kWh/d. Delivering the stuff costs 12 kWh/d.

4 Wind

The UK has the best wind resources in Europe.
Sustainable Development Commission

Wind farms will devastate the countryside pointlessly.
James Lovelock

How much wind power could we plausibly generate?

We can make an estimate of the potential of *on-shore* (land-based) wind in the United Kingdom by multiplying the average power per unit land-area of a wind farm by the area per person in the UK:

power per person = wind power per unit area × area per person.

Chapter B (p263) explains how to estimate the power per unit area of a wind farm in the UK. If the typical windspeed is 6 m/s (13 miles per hour, or 22 km/h), the power per unit area of wind farm is about 2 W/ m^2.

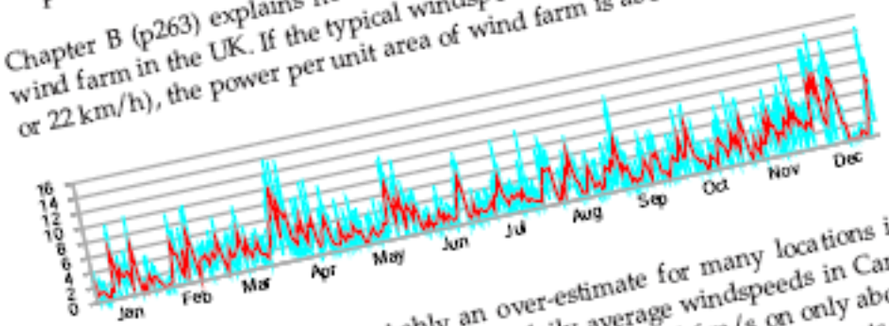

Figure 4.1. Cambridge mean wind speed in metres per second, daily (red line), and half-hourly (blue line) during 2006. See also figure 4.6.

This figure of 6 m/s is probably an over-estimate for many locations in Britain. For example, figure 4.1 shows daily average windspeeds in Cambridge during 2006. The daily average speed reached 6 m/s on only about 30 days of the year – see figure 4.6 for a histogram. But some spots do have windspeeds above 6 m/s – for example, the summit of Cairngorm in Scotland (figure 4.2).

Plugging in the British population density: 250 people per square kilometre, or 4000 square metres per person, we find that wind power could

Cairngorm mean wind

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Sustainable Energy – without the ho

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/m².

ovided by a square 100 km by 100 km
ncentrating solar power in deserts delivers
area of roughly 15 W/m². So, allowing
h a square, the power delive
as current world

Figure 25.3. Stirling dish engine. These beautiful concentrato
a power per

Time is short. We urgently need clear thinking, huge investment, and effective leadership.

Jeroen van der Veer
Chief Executive
Royal Dutch Shell plc

Sustainable Energy

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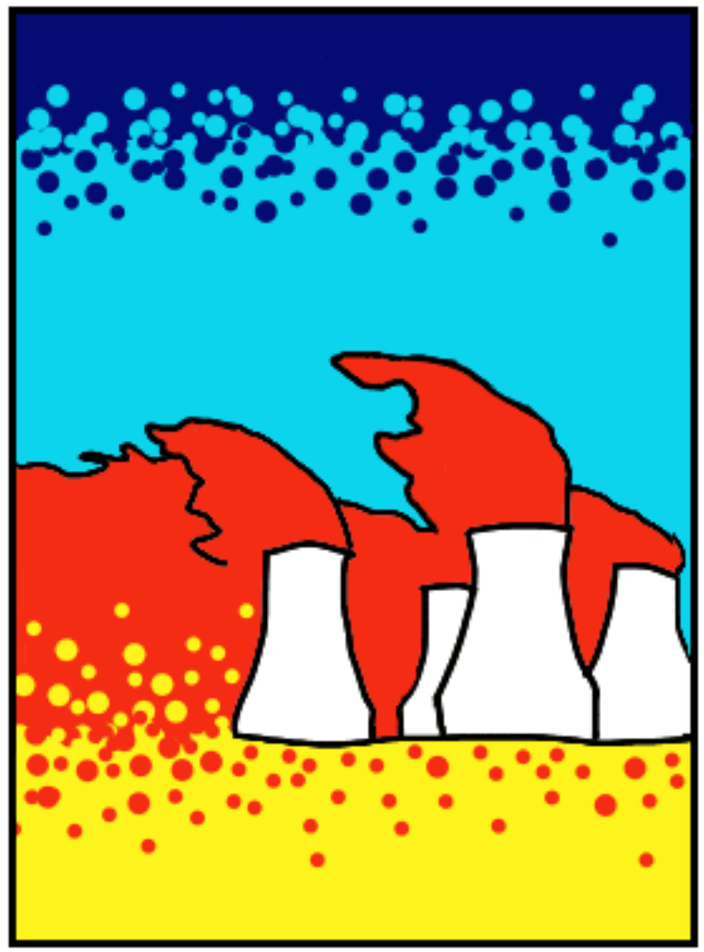
Biofuels



David MacKay

Department of Physics
University of Cambridge

www.withouthotair.com

It is a crime against humanity to convert food crops to fuel

Jean Ziegler,
UN Special Rapporteur on the Right to Food.

The world should wake up to the dangers of the mass production of biofuels

Professor Sir Peter Crane,
Director, Royal Botanic Gardens, Kew.

Biofuel boom 'to raise beer price'

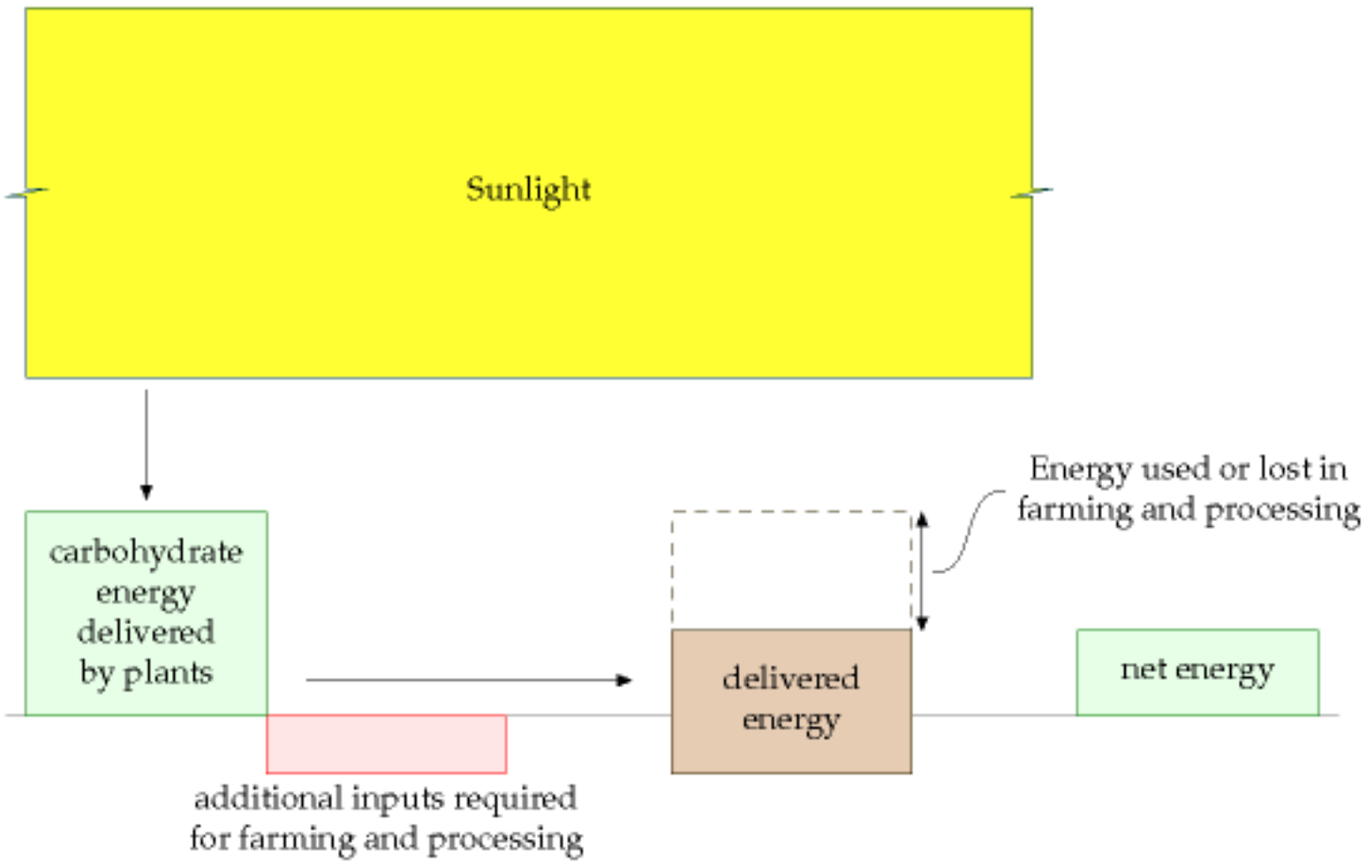
BEER drinkers could face a rise in the price of a pint because farmers are planting crops for green fuels instead of barley. Rising demand for corn, soya beans and rapeseed for use in biofuels is making farmers move away from barley, a key ingredient in brewing. The price of barley has soared in the past year. Heineken chief executive Jean-François van Boxmeere said a long-term rise in beer prices was likely as a result.

Biofuels worsen global warming

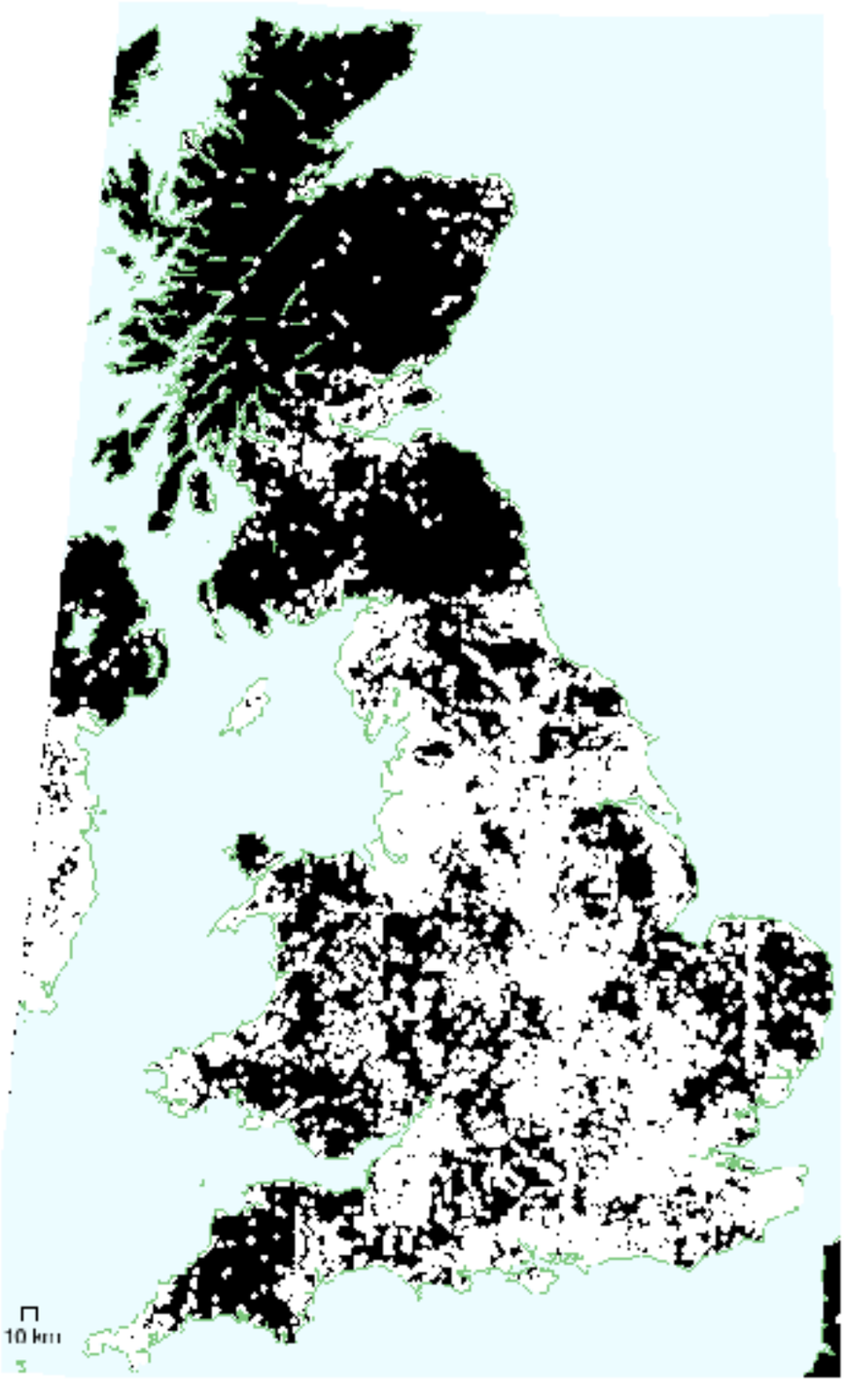
- Borneo - peat-burning
- Rape-seed - nitrous oxide

How much power could Britain get from biofuels?

Power per unit area



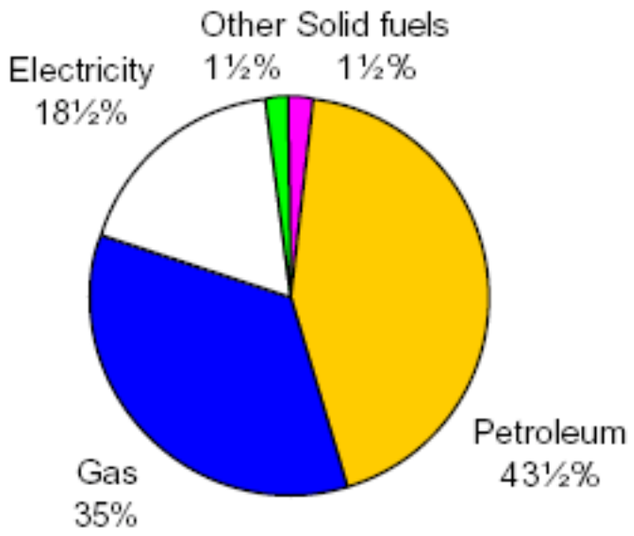
x Area



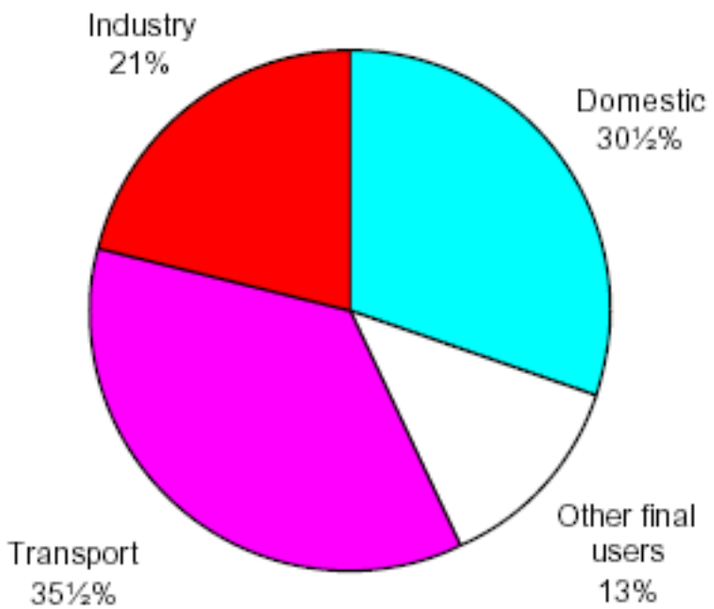
Attention is sometimes focussed on the comparison of the other inputs with the delivered energy

For corn-ethanol, the required inputs and losses are so big, it's difficult to make the Net Energy positive!

Average power consumption, UK: 125 kWh/d/p



2004



www.dti.gov.uk

'primary consumption'

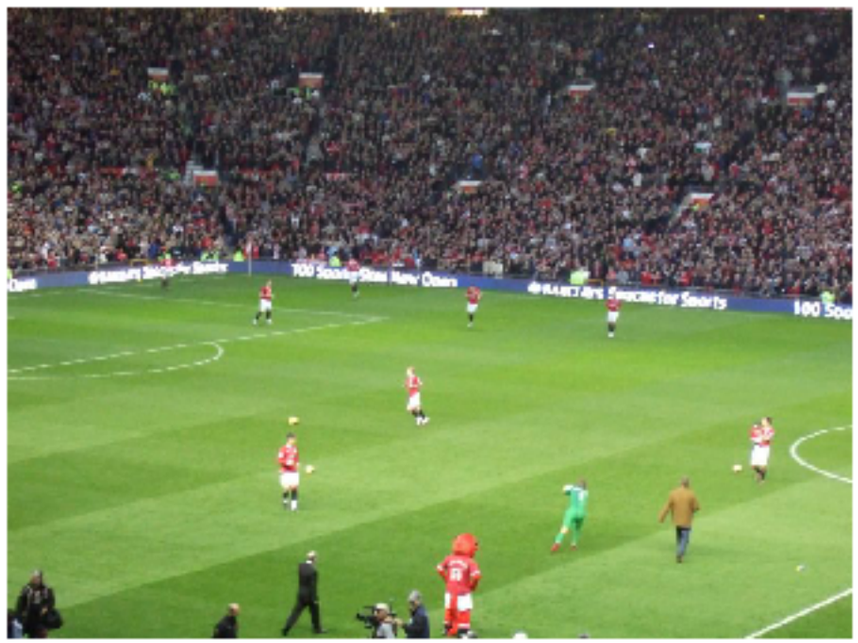
125 kWh/day (Europe)

250 kWh/day (USA)

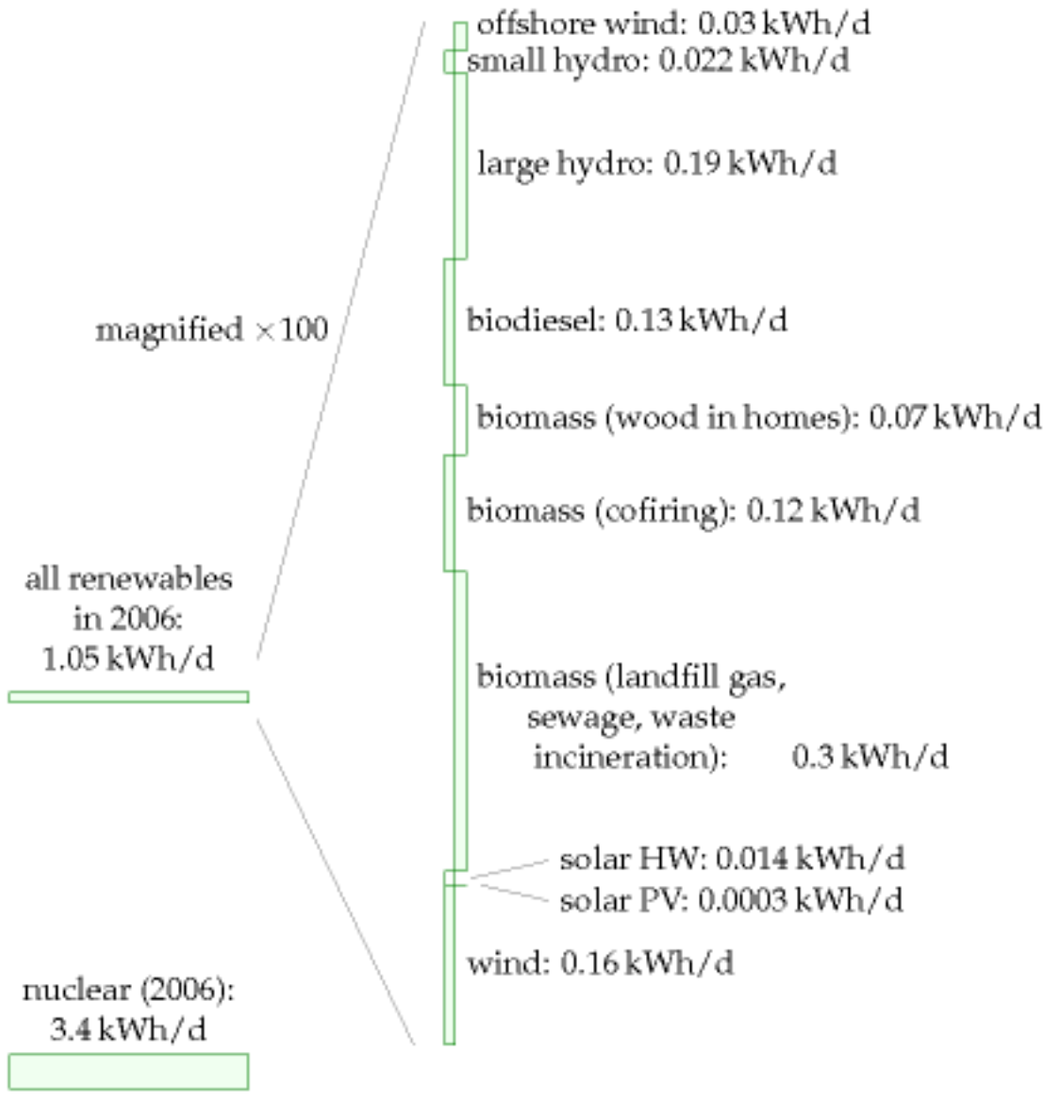
(doesn't include imports,
nor solar energy in food)

Area

UK: 4000 m^2 per person

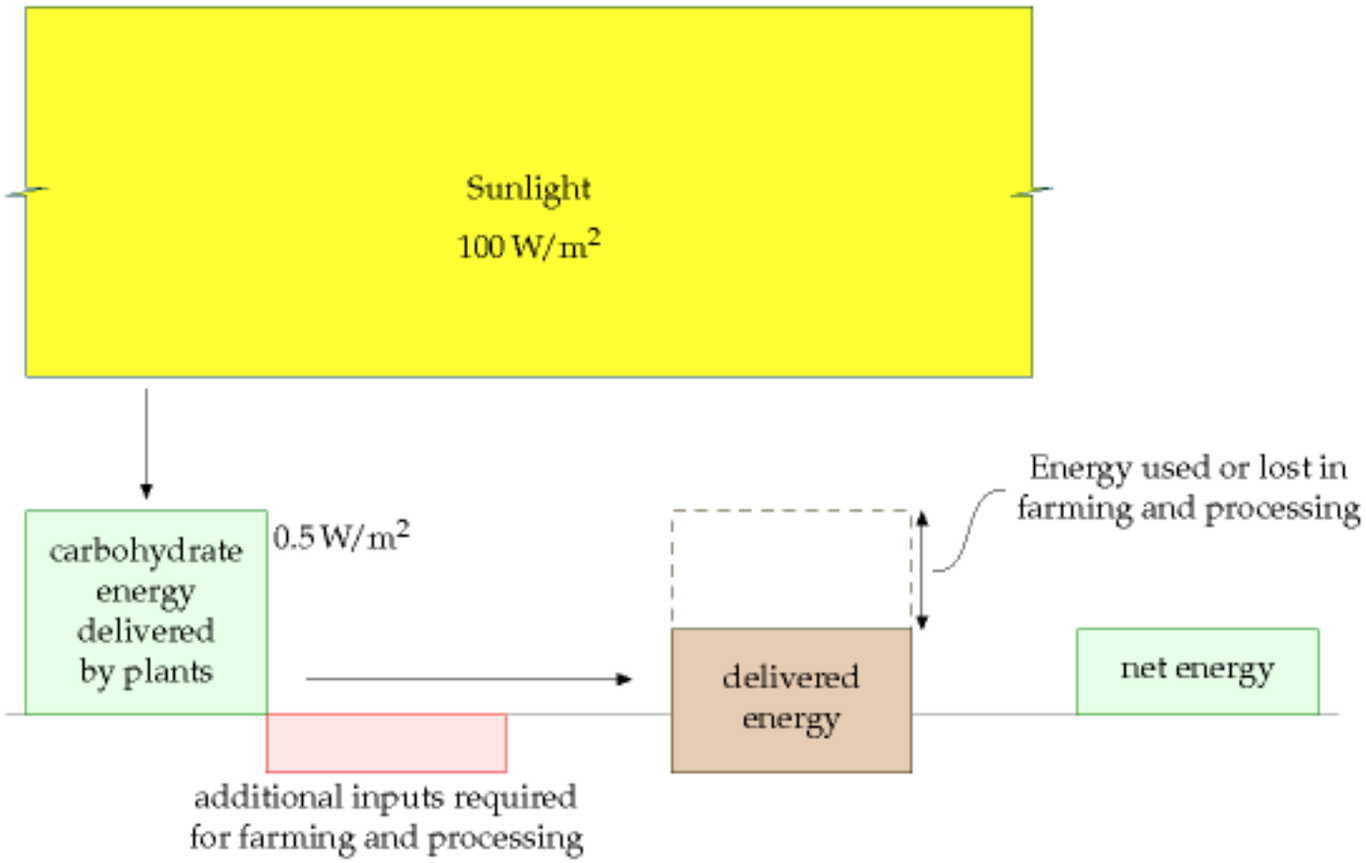


Today's supply of renewables



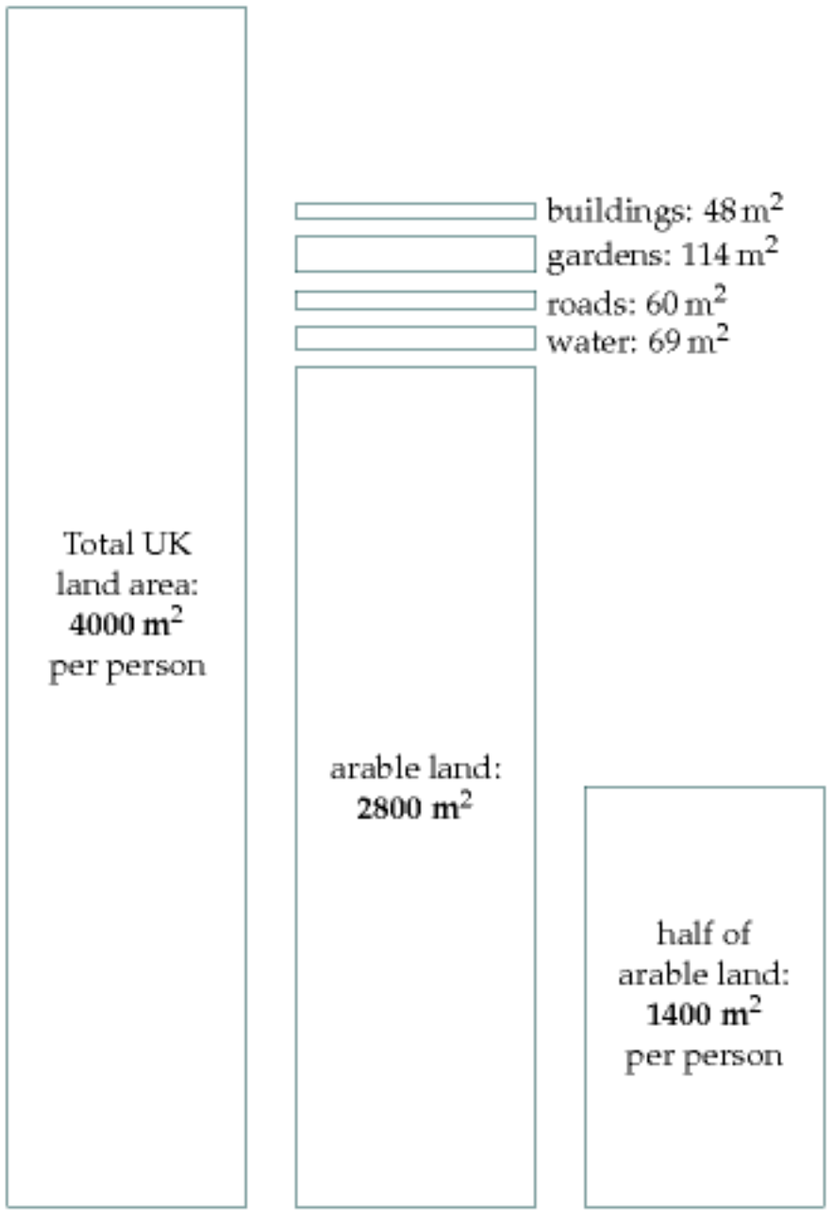
How much power could Britain get from biofuels?

Power per unit area



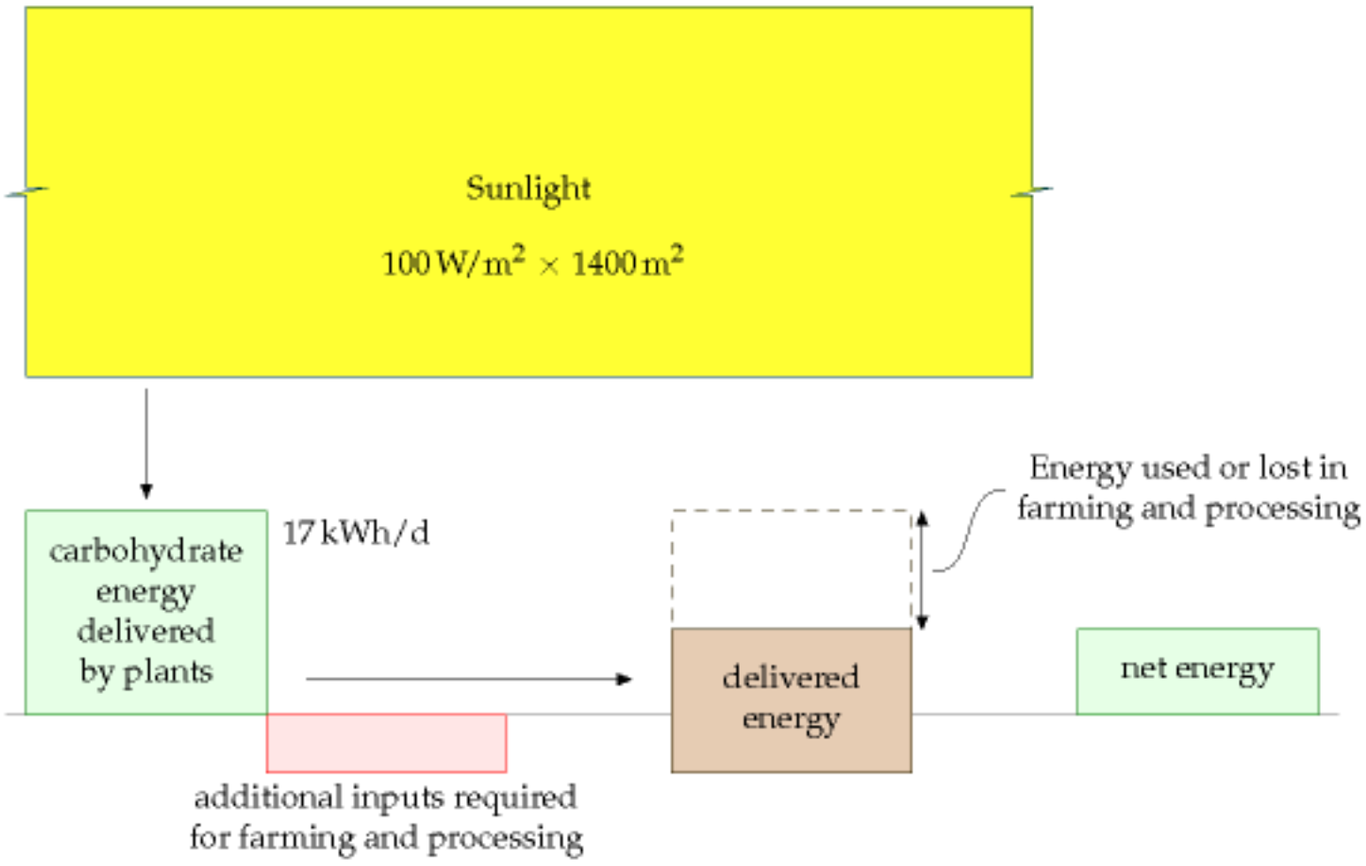
Taking the most efficient plants

x Area

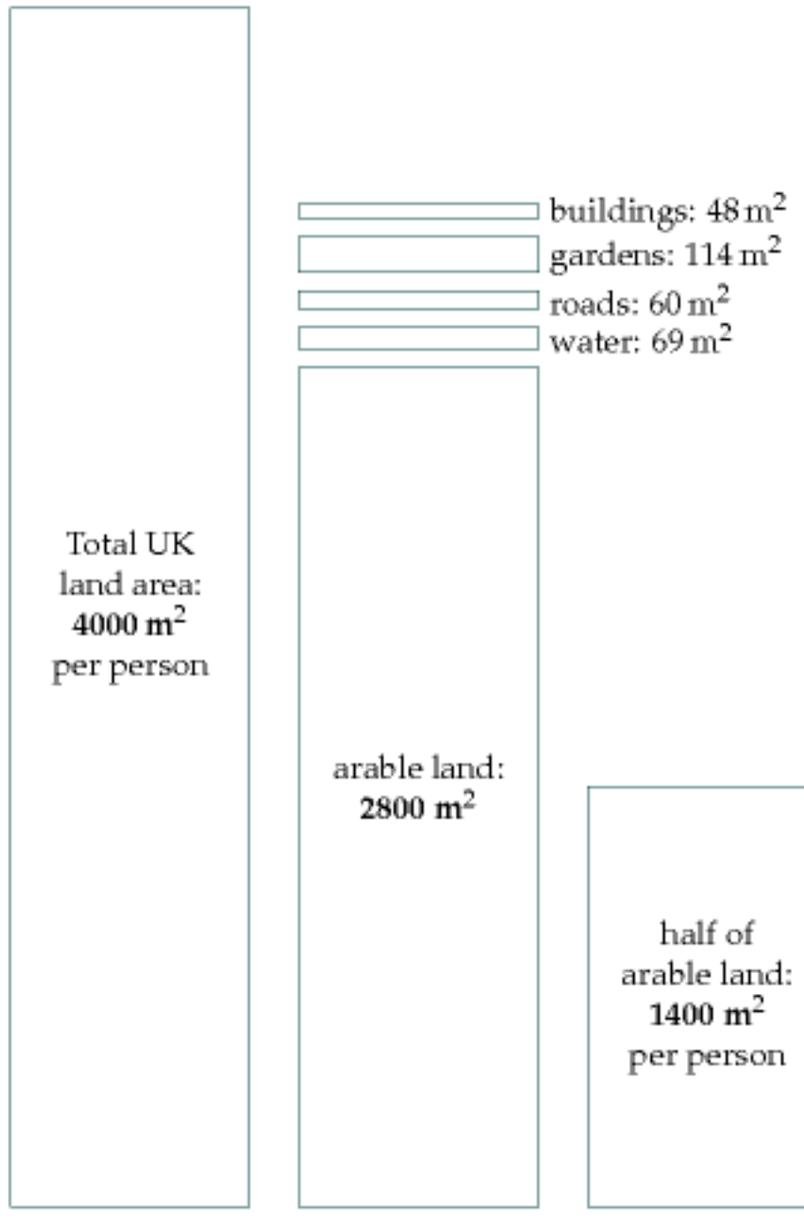


How much power could Britain get from biofuels?

Power per unit area

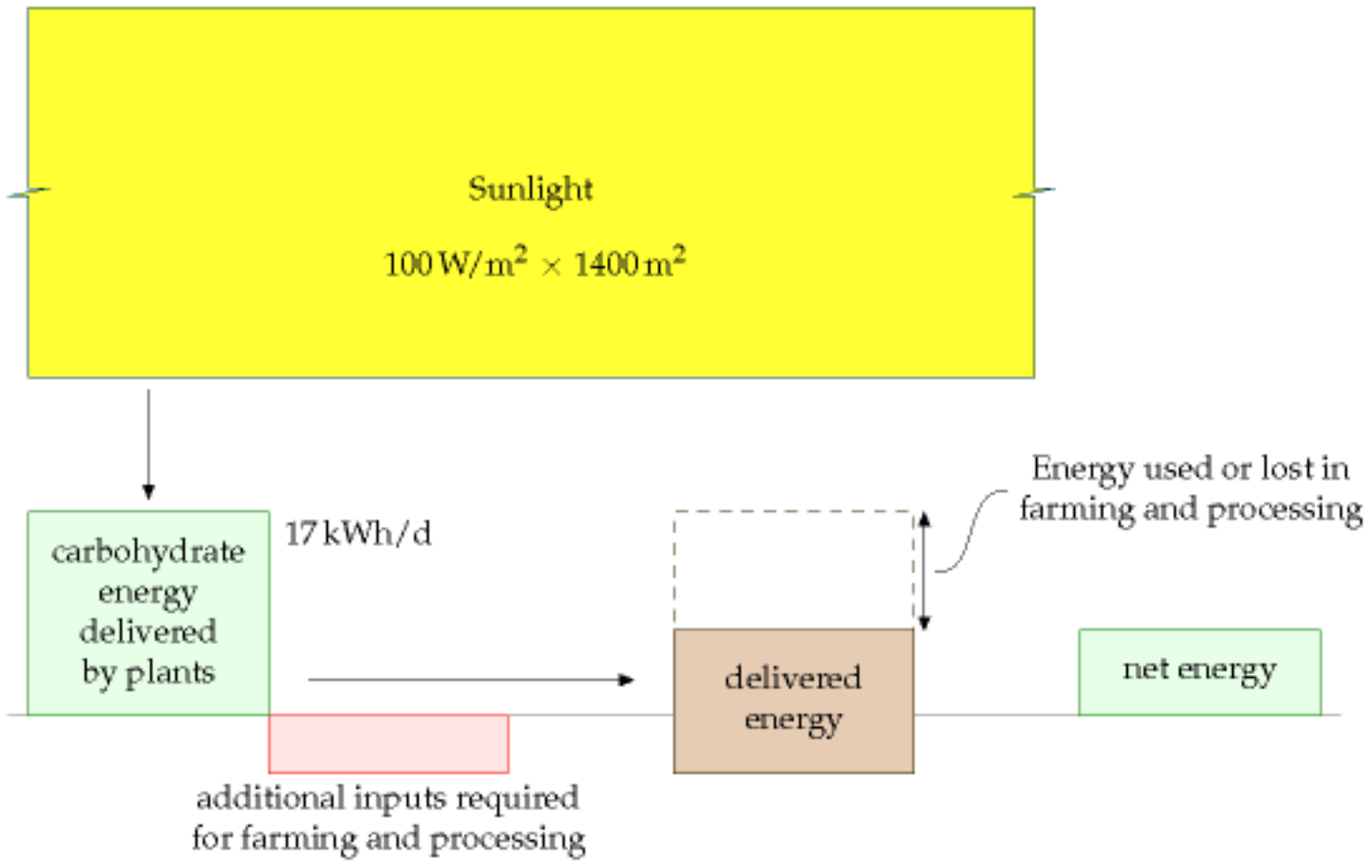


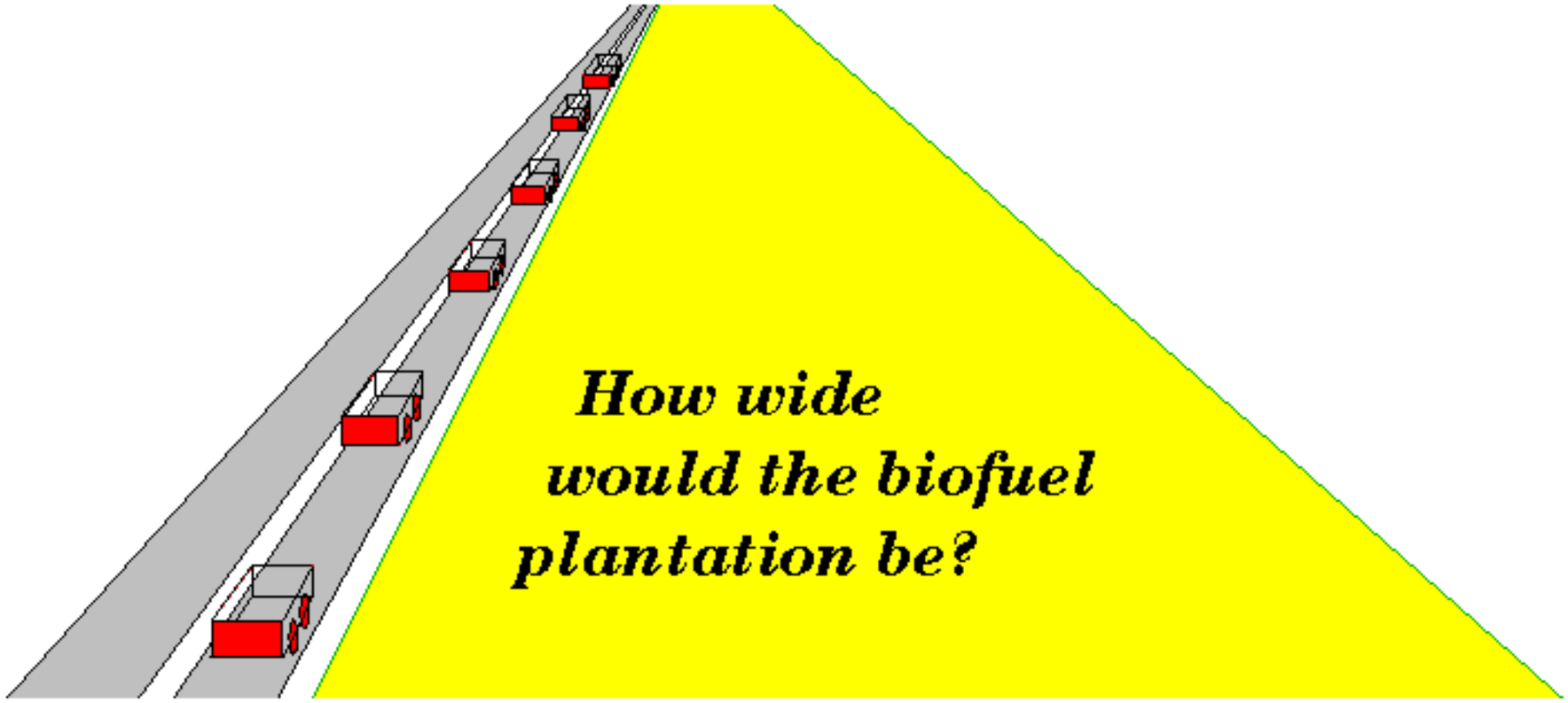
x Area



Even if all the other issues were resolved

- Biofuels could make only a small contribution





One lane of cars

60 miles per hour

30 miles per gallon

1200 litres of biofuel per hectare per year

80 metres car-spacing

8 kilometres wide

References

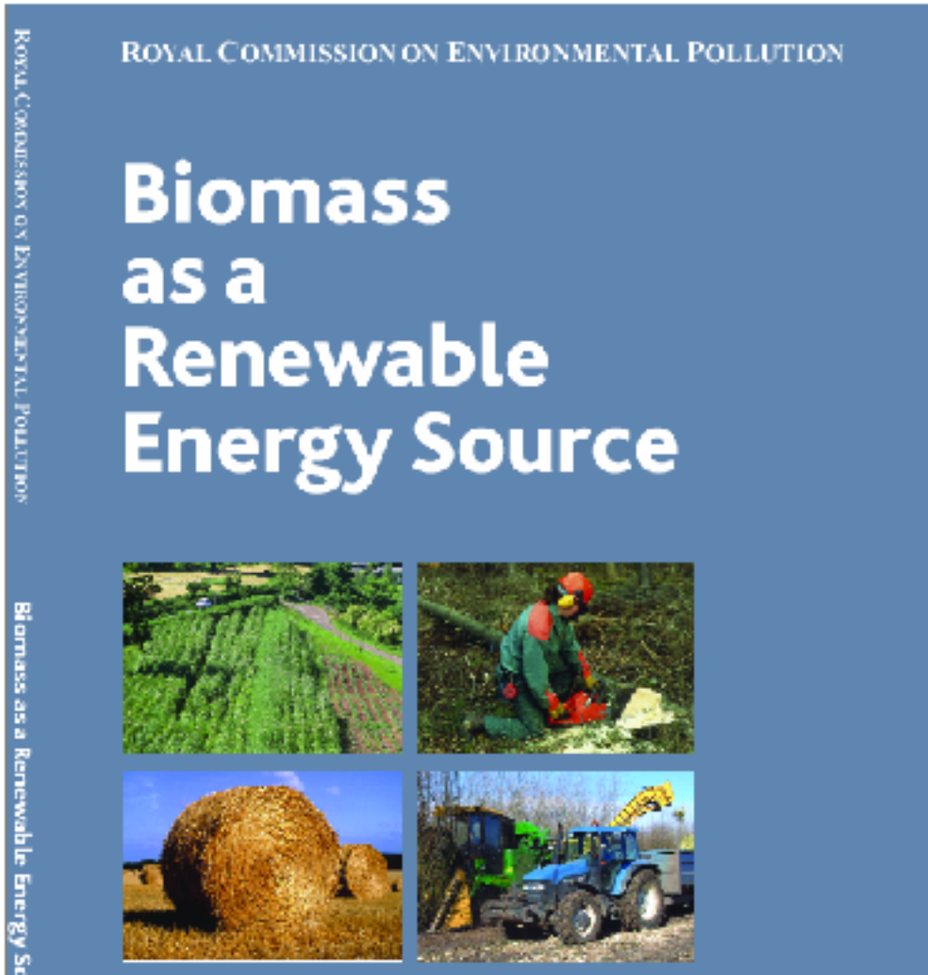
http://www.grain.org/front/
http://www.grain.org/agrofuels/
http://www.grain.org/seedling_files/seed-07-07-2-en.pdf

"Even if the USA's entire corn and soya harvests were used to produce agrofuels, they would satisfy only 12 per cent of the USA's current thirst for petrol and 6 per cent of its need for diesel. The situation in Europe is even worse: the UK, for example, could not grow enough agrofuels to run all its cars even if it put the whole country under the plough."

MIT lifecycle analysis (Groode and Heywood):
http://lfee.mit.edu/metadot/index.pl?id=2234

Alex Farrell, Science, DOI:10.1126/science.1121416

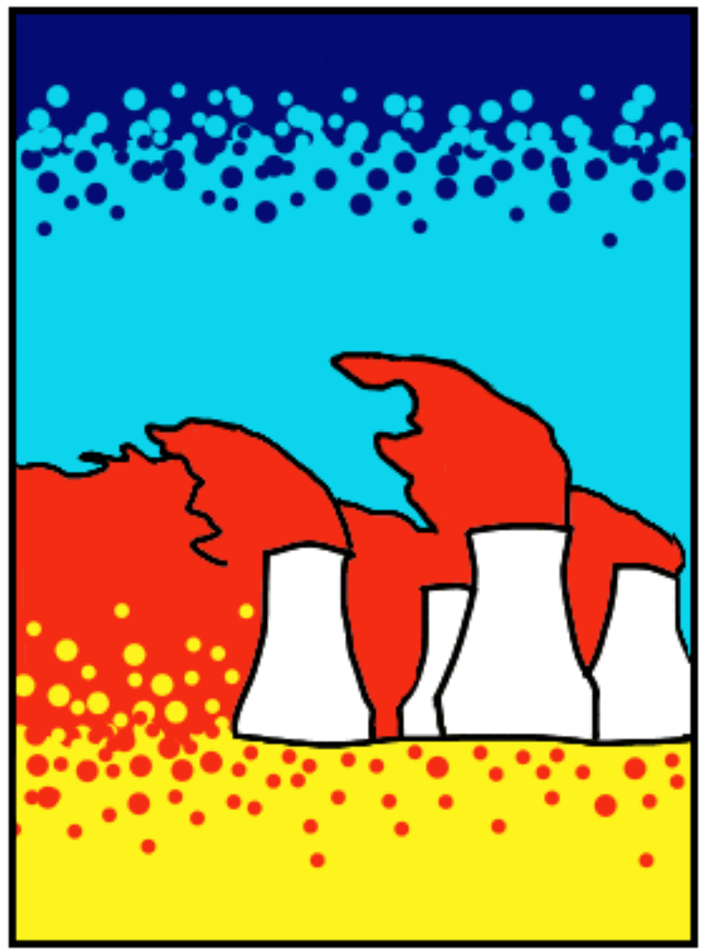
H. Shapouri, J.A. Duffield, and Michael S. Graboski,
Estimating the Net Energy Balance of Corn Ethanol
United States Department of Agriculture,
Agricultural Economic Report Number 721

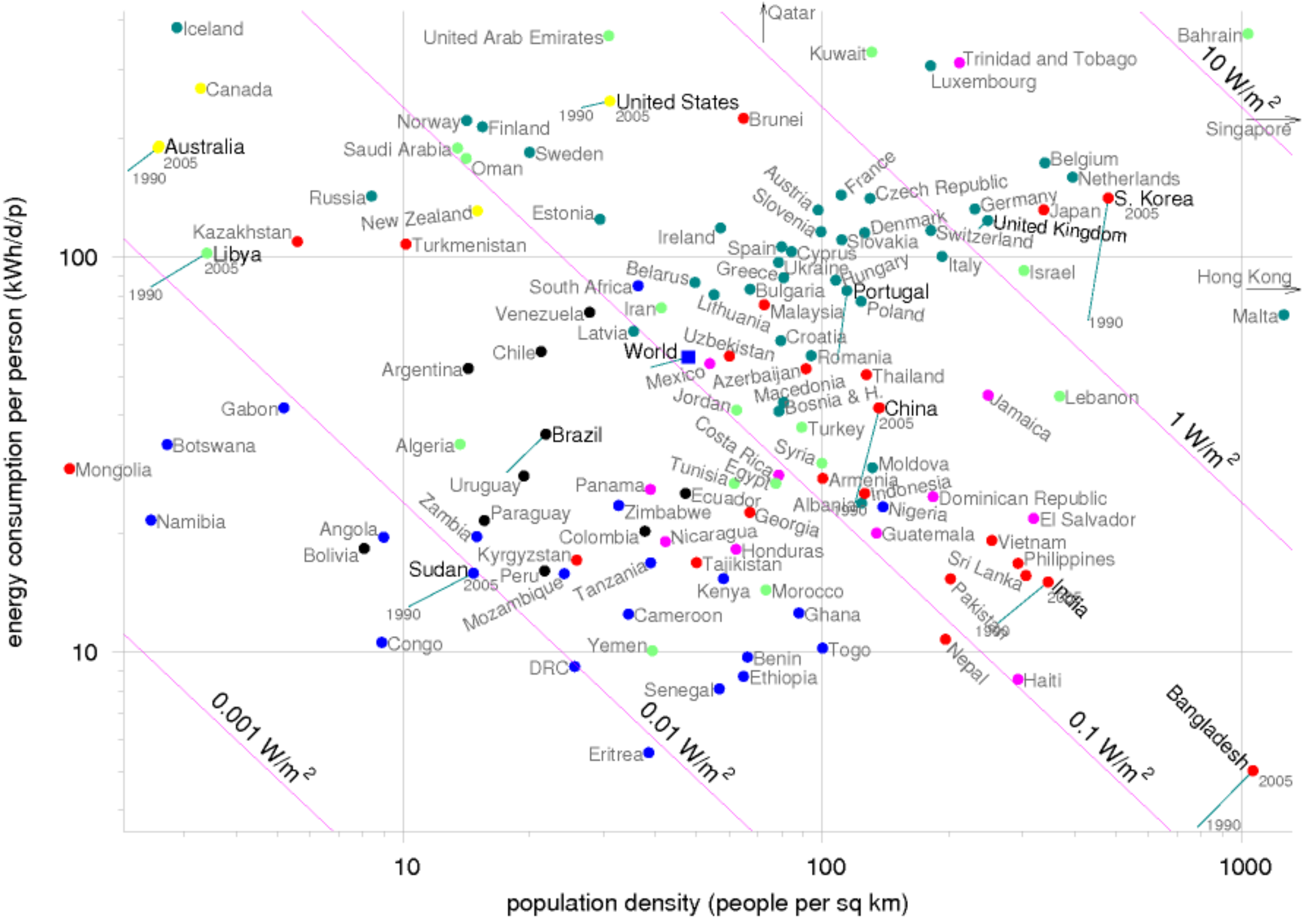


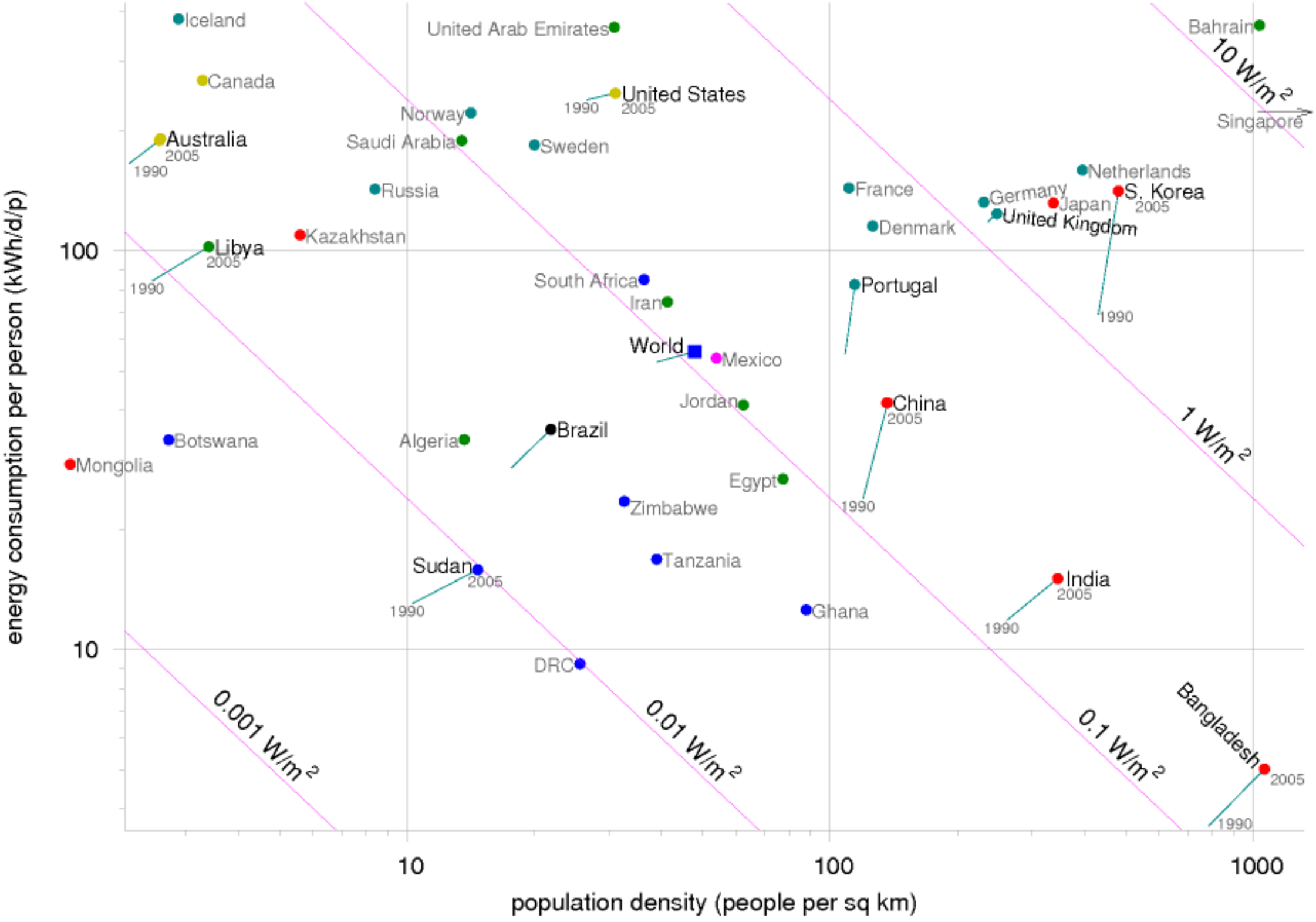
Sustainable Energy

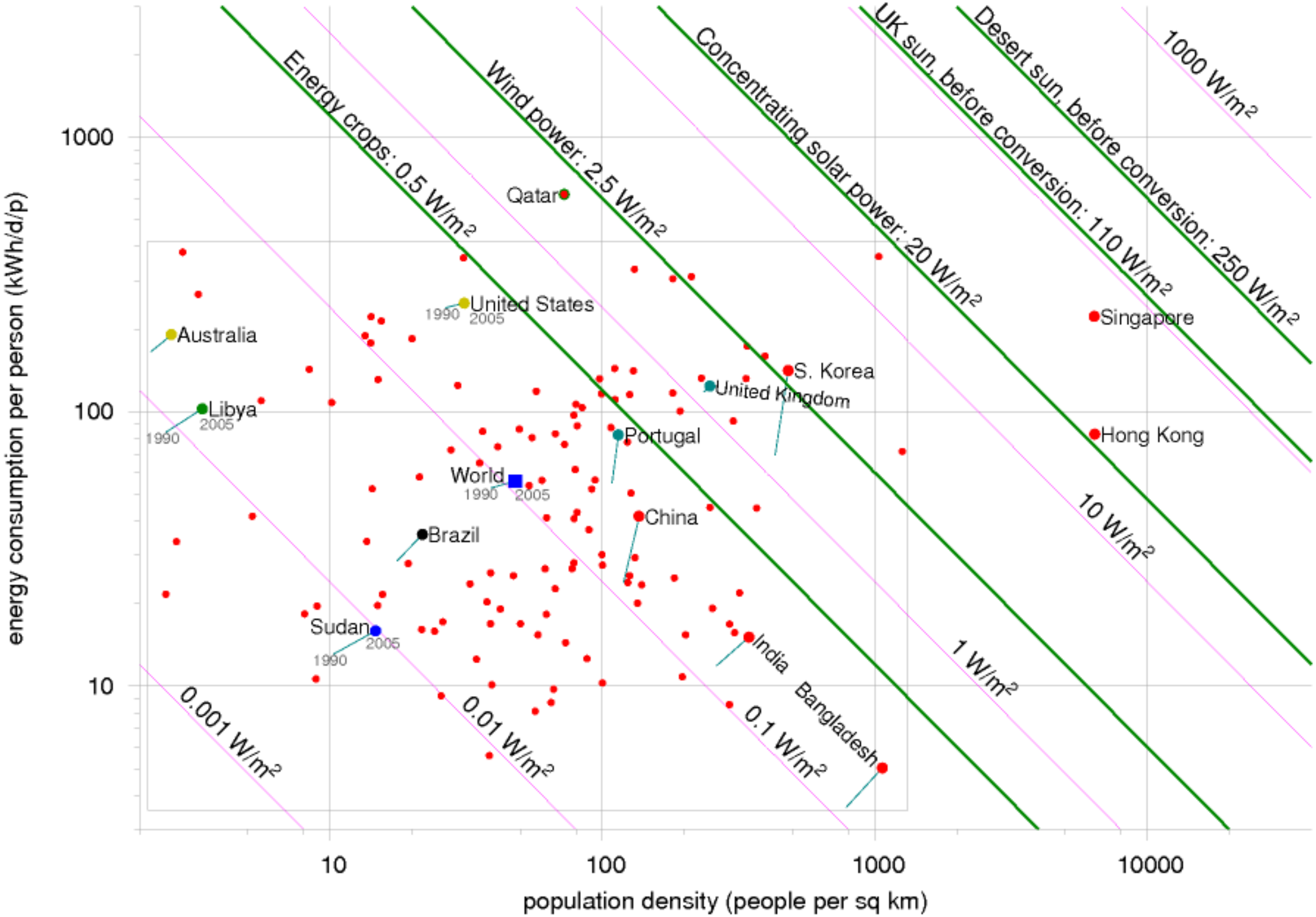
- without the hot air

The whole talk in one graph




energy consumption per person (kWh/d/p)
100
10
population density (people per sq km)
10
100
1000
Qatar
Iceland
United Arab Emirates
Kuwait
Trinidad and Tobago
Luxembourg
Bahrain
10 W/m²
Singapore
Canada
United States
1990
2005
Brunei
Norway
Finland
Australia
2005
1990
Saudi Arabia
Oman
Sweden
Belgium
Netherlands
Russia
Austria
France
Czech Republic
Germany
S. Korea
Slovenia
Japan
2005
Estonia
New Zealand
Denmark
United Kingdom
Switzerland
Kazakhstan
Ireland
Slovakia
Libya
2005
1990
Turkmenistan
Spain
Cyprus
Italy
Israel
Greece
Ukraine
Hungary
Belarus
Portugal
Hong Kong
South Africa
Bulgaria
Malaysia
Poland
Malta
Venezuela
Iran
Lithuania
1990
Latvia
Croatia
Uzbekistan
Chile
World
Romania
Argentina
Mexico
Azerbaijan
Thailand
Macedonia
Jordan
Bosnia & H.
Lebanon
Gabon
China
2005
Jamaica
Turkey
Brazil
Botswana
Algeria
Costa Rica
Syria
Moldova
Mongolia
Tunisia
Egypt
Armenia
Uruguay
Panama
Indonesia
Ecuador
Albania
1990
Dominican Republic
Zambia
Paraguay
Zimbabwe
Nigeria
Georgia
El Salvador
Namibia
Angola
Colombia
Nicaragua
Guatemala
Vietnam
Bolivia
Honduras
Philippines
Kyrgyzstan
Sri Lanka
Sudan
2005
Peru
Tajikistan
India
Mozambique
Tanzania
Pakistan
1990
Kenya
Morocco
Cameroon
Ghana
Congo
Yemen
Togo
Nepal
Benin
DRC
Ethiopia
Haiti
Senegal
0.001 W/m²
0.01 W/m²
0.1 W/m²
Bangladesh
2005
Eritrea
1990


energy consumption per person (kWh/d/p)
100
10
10
100
1000
population density (people per sq km)
Iceland
Canada
Australia
2005
1990
United Arab Emirates
United States
1990
2005
Norway
Saudi Arabia
Sweden
Russia
Kazakhstan
Libya
2005
1990
South Africa
Iran
World
Mexico
Jordan
Botswana
Mongolia
Algeria
Brazil
Egypt
Zimbabwe
Sudan
2005
1990
Tanzania
Ghana
DRC
Bahrain
10 W/m²
Singapore
France
Netherlands
Germany
Japan
S. Korea
2005
United Kingdom
Denmark
Portugal
1990
China
2005
1990
1 W/m²
India
2005
1990
Bangladesh
2005
1990
0.001 W/m²
0.01 W/m²
0.1 W/m²


energy consumption per person (kWh/d/p)
1000
100
10
population density (people per sq km)
10
100
1000
10000
Energy crops: 0.5 W/m²
Wind power: 2.5 W/m²
Concentrating solar power: 20 W/m²
UK sun, before conversion: 110 W/m²
Desert sun, before conversion: 250 W/m²
1000 W/m²
10 W/m²
1 W/m²
0.1 W/m²
0.01 W/m²
0.001 W/m²
Qatar
United States
1990
2005
Australia
Libya
1990
2005
S. Korea
United Kingdom
Singapore
Hong Kong
Portugal
World
1990
2005
China
Brazil
Sudan
1990
2005
India
Bangladesh

We have an addiction to fossil fuels, and it's not sustainable

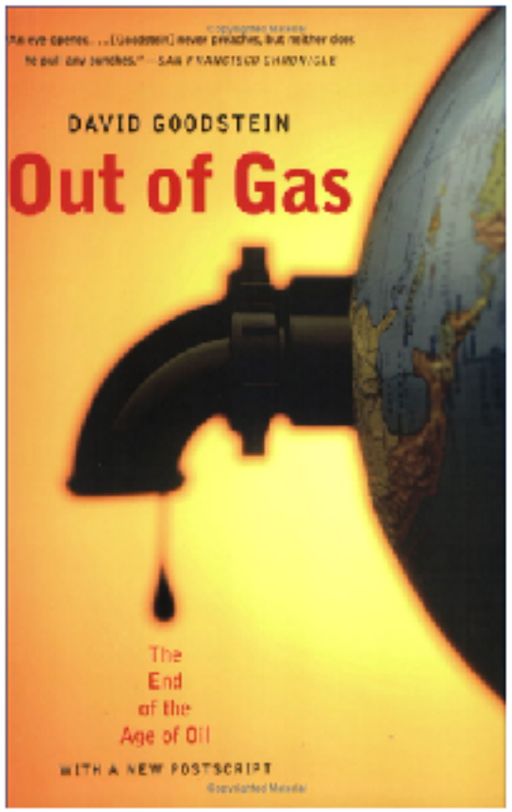
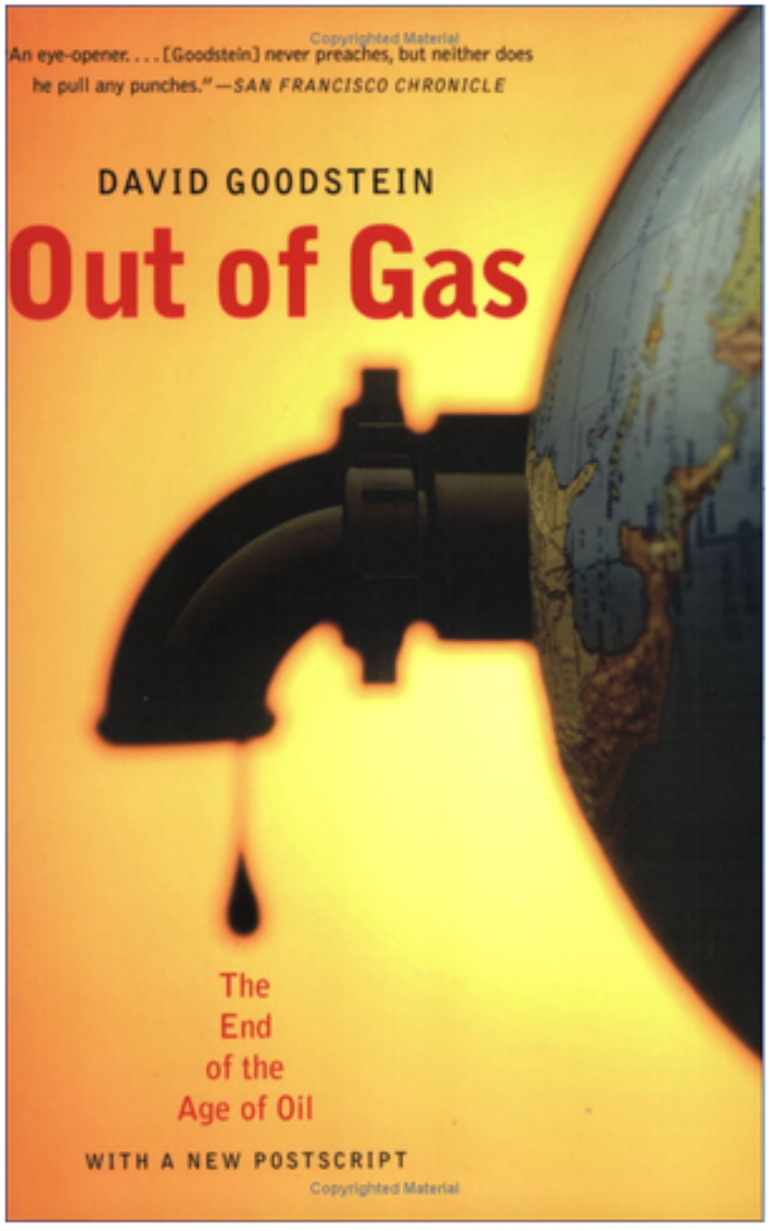


Photo by Terry Cavner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An eye-opener. . . . [Goodstein] never preaches, but neither does he pull any punches." —SAN FRANCISCO CHRONICLE
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The End of the Age of Oil
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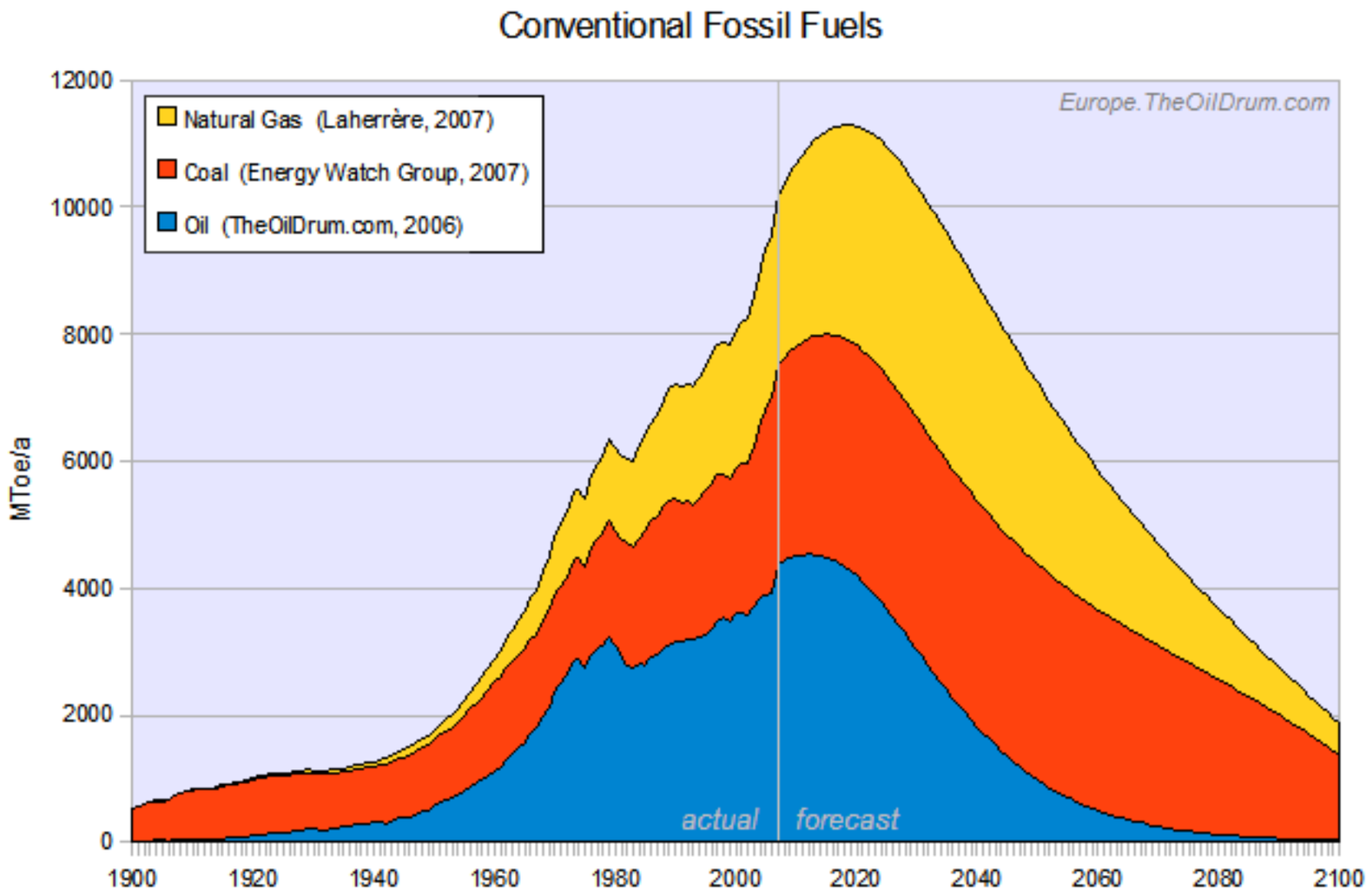

Conventional Fossil Fuels
Europe.TheOilDrum.com
Natural Gas (Laherrère, 2007)
Coal (Energy Watch Group, 2007)
Oil (TheOilDrum.com, 2006)
MToe/a
12000
10000
8000
6000
4000
2000
0
actual
forecast
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100

We have an addiction to fossil fuels, and it's not sustainable

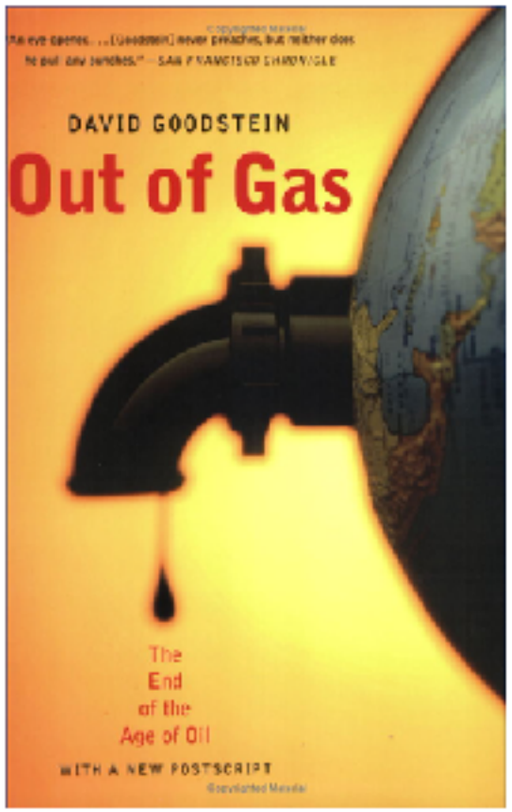


Photo by Terry Cavner

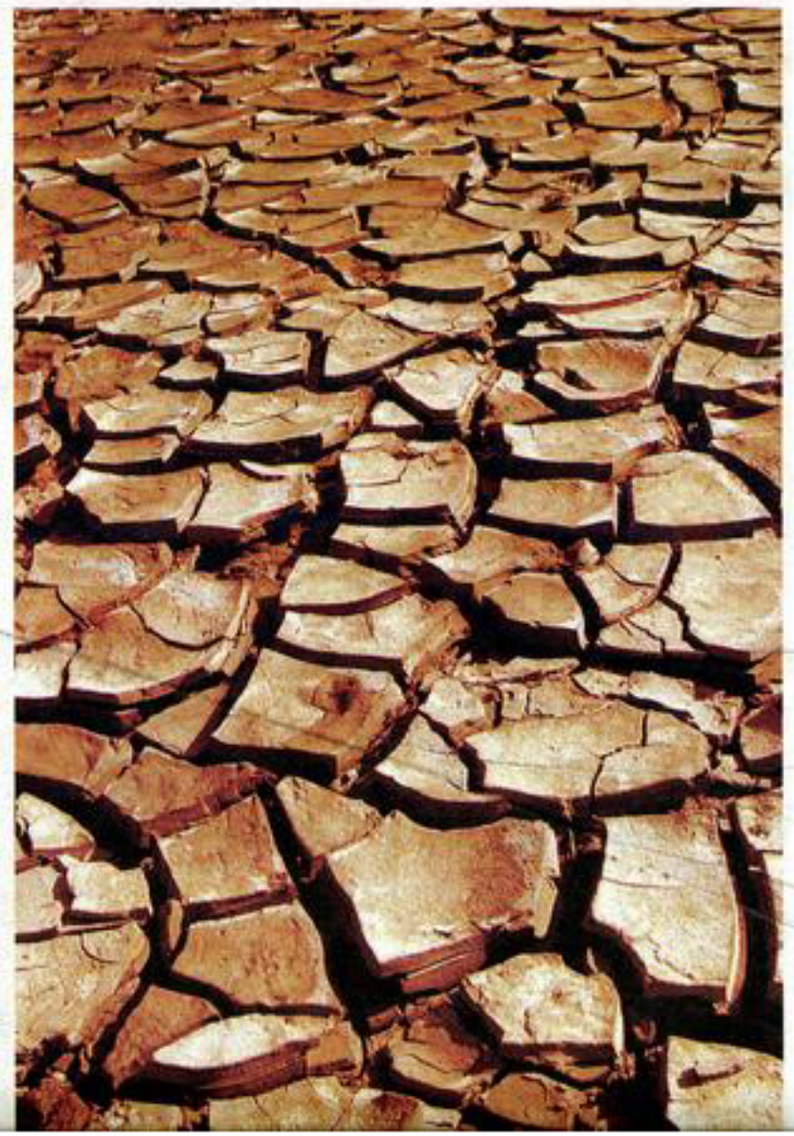
Newspaper of the Year

THE INDEPENDENT

No 5,700 www.independent.co.uk MONDAY 24 JANUARY 2005 ★ (Republic of Ireland €0.95) 60p

● Climate change: report warns point of no return may be reached in 10 years, leading to droughts, agricultural failure and water shortages

Countdown to global catastrophe



By Michael McCarthy
Environment Editor

THE GLOBAL warming danger threshold for the world is clearly marked for the first time in an international report to be published tomorrow – and the bad news is, the world has nearly reached it already.

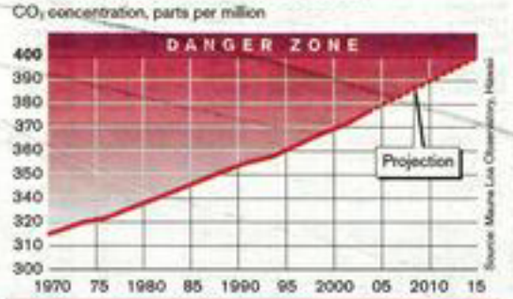
The countdown to climate-change catastrophe is spelt out by a task force of senior politicians, business leaders and academics from around the world – and it is remarkably brief. In as little as 10 years, or even less, their report indicates, the point of no return with global warming may have been reached.

The report, *Meeting The Climate Challenge*, is aimed at policymakers in every country, from national leaders down. It has been timed to coincide with Tony Blair's promised efforts to advance climate change policy in 2005 as chairman of both the G8 group of rich countries and the European Union.

And it breaks new ground by putting a figure – for the first time in such a high-level docu-

ATMOSPHERIC CARBON DIOXIDE

CO_2 concentration, parts per million

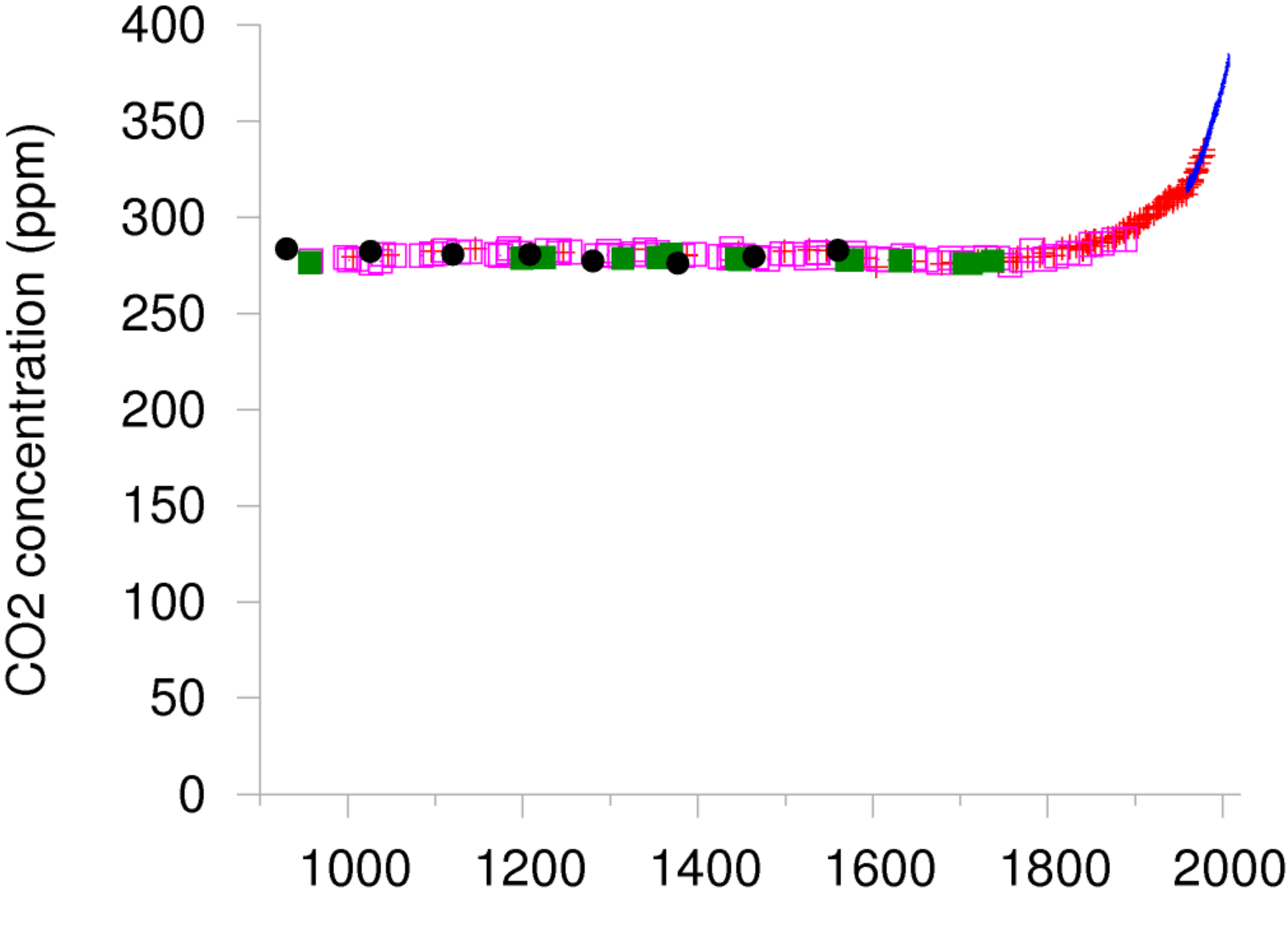


changes. These could include widespread agricultural failure, water shortages and major droughts, increased disease, sea-level rise and the death of forests – with the added possibility of abrupt catastrophic events such as "runaway" global warming, the melting of the Greenland ice sheet, or the switching-off of the Gulf Stream.

The report says this point will be two degrees centigrade above the average world temperature prevailing in 1750 before the industrial revolution,

to affect the climate. But it points out that global average temperature has already risen by 0.8 degrees since then, with more rises already in the pipeline – so the world has little more than a single degree of temperature latitude before the crucial point is reached.

More ominously still, it assesses the concentration of carbon dioxide in the atmosphere after which the two-degree rise will become inevitable, and says it will be 400 parts per million by volume (ppm) of CO_2.

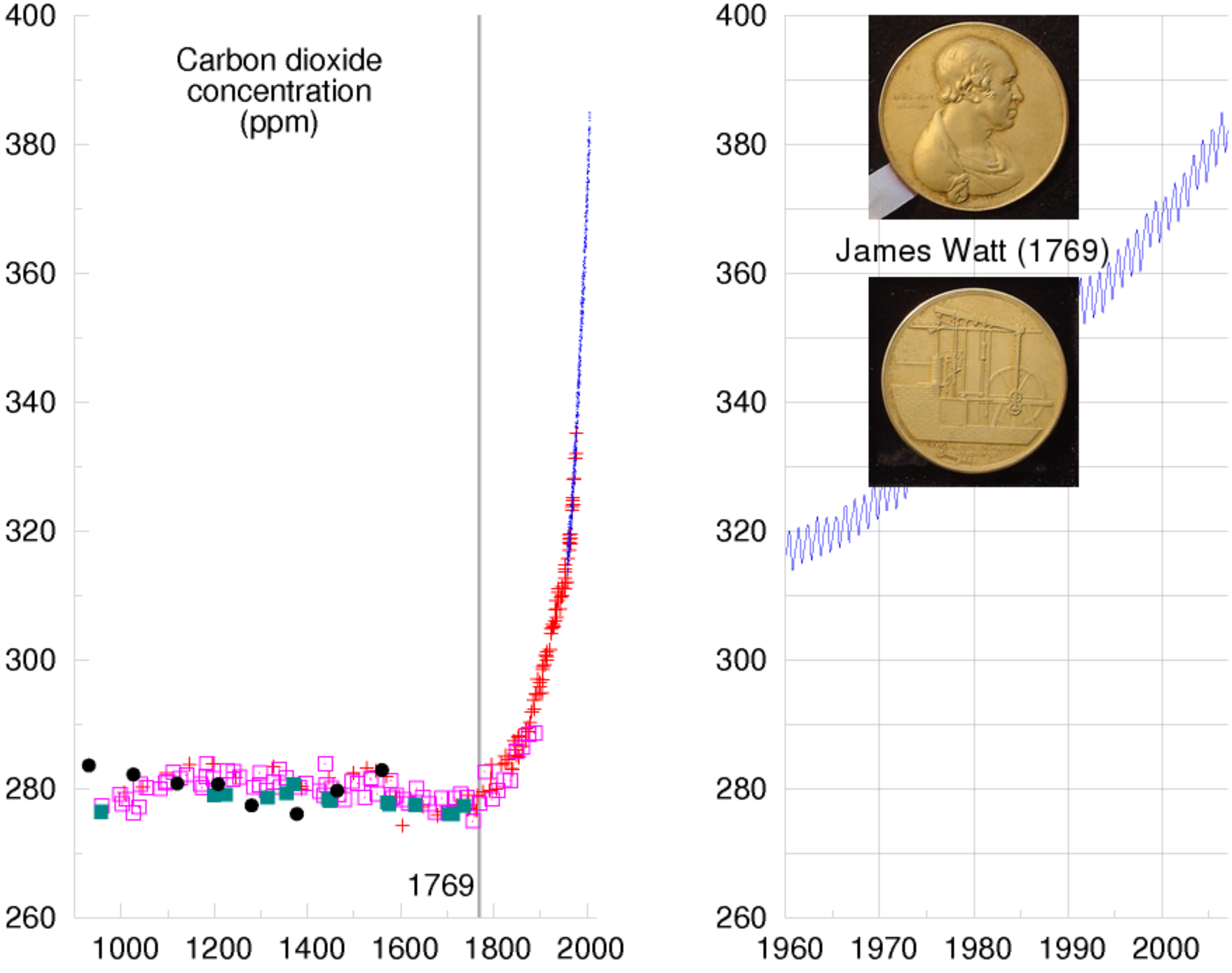

CO2 concentration (ppm)
400
350
300
250
200
150
100
50
0
1000
1200
1400
1600
1800
2000

Carbon dioxide concentration (ppm)

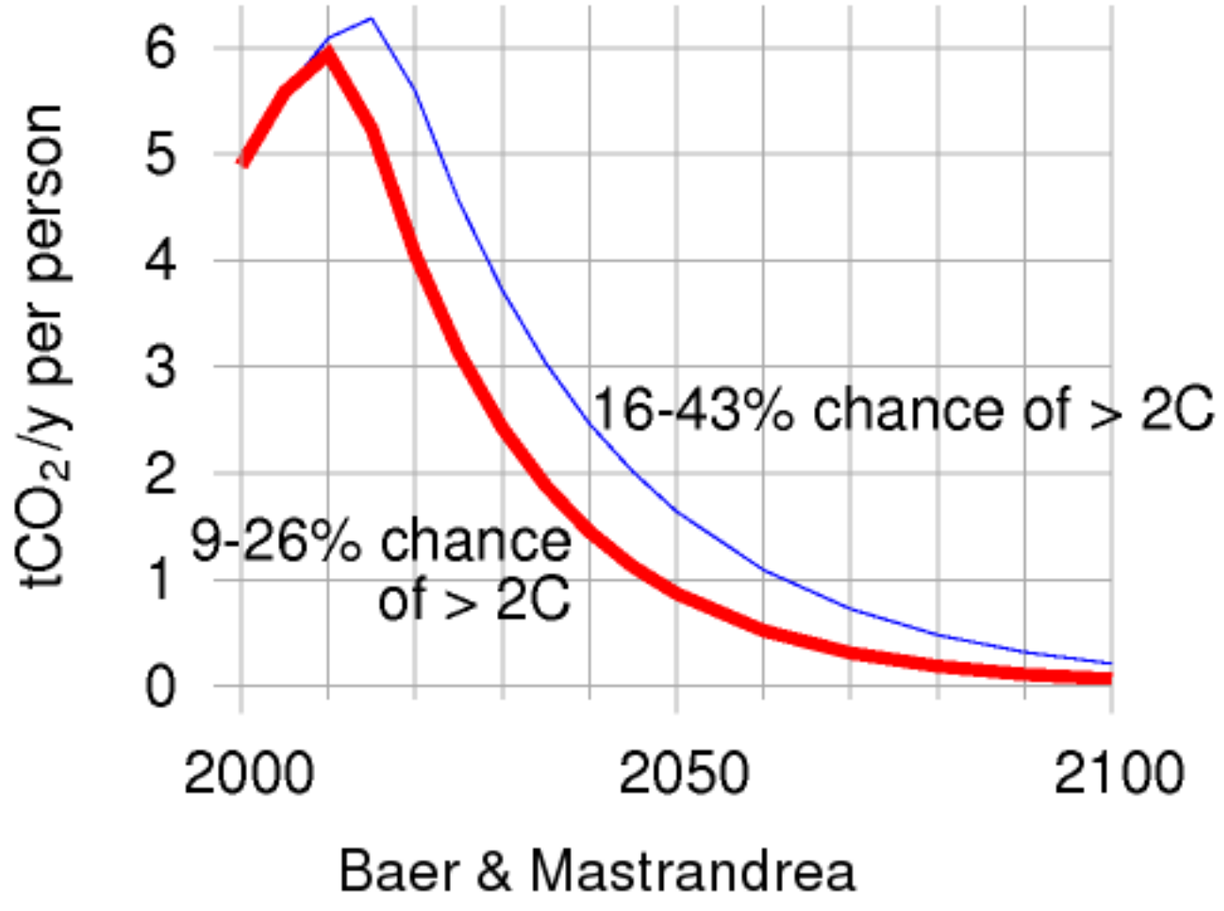
400
380
360
340
320
300
280
260
1000
1200
1400
1600
1800
2000

400
380
360
340
320
300
280
260
1960
1970
1980
1990
2000

Sources: Keeling and Whorf (2005); Neftel et al (1994); Etheridge et al (1998); Siegenthaler et al (2005); Indermuhle et al (1999)

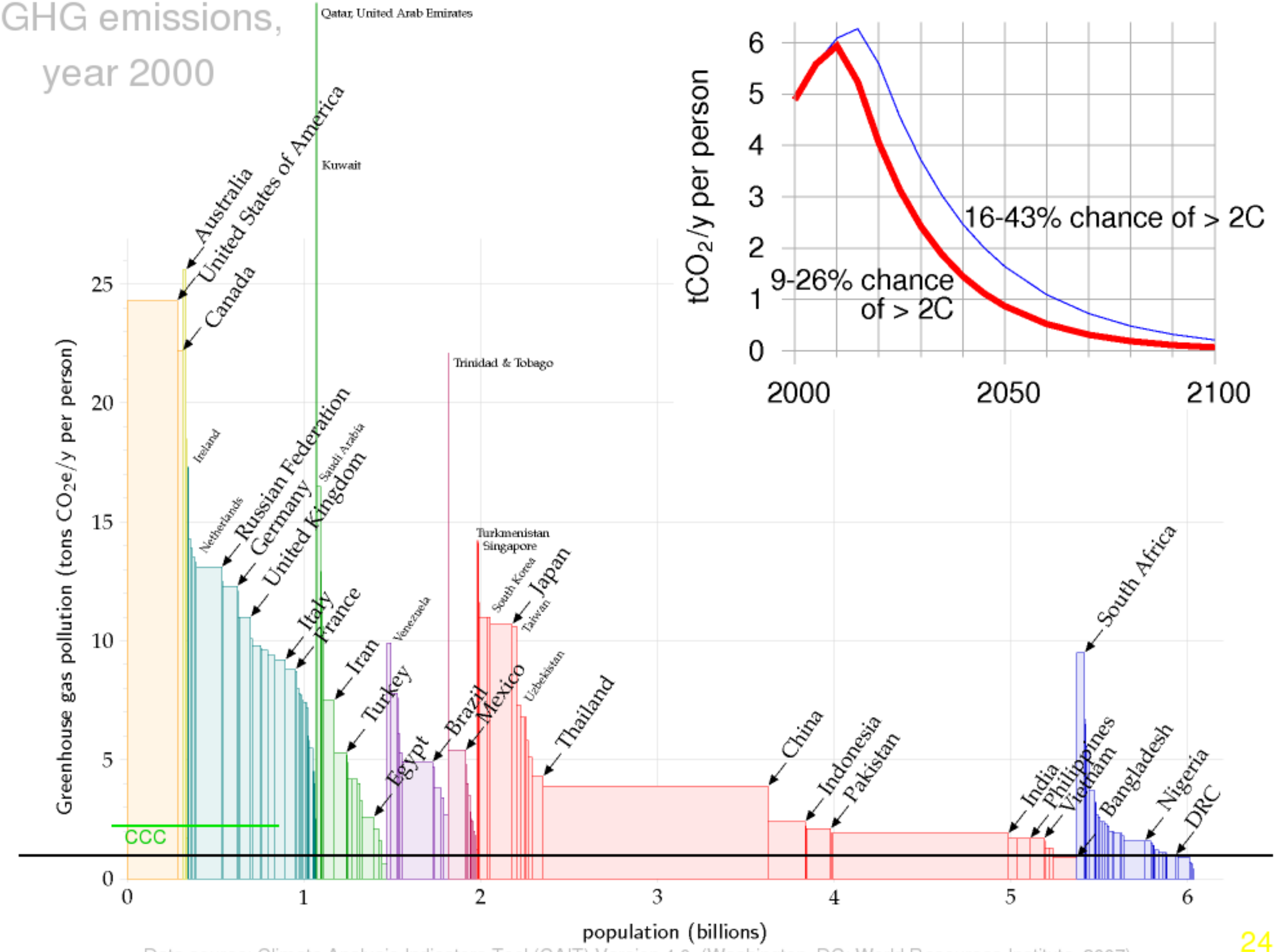


Sources: Keeling and Whorf (2005); Neftel et al (1994); Etheridge et al (1998); Siegenthaler et al (2005); Indermuhle et al (1999)



Climate scientists recommend reduction
from $5.5\,\mathrm{t\,CO_2}$ per year per person (world average)
to $\sim 1\,\mathrm{t\,CO_2}$ per year per person by 2050

GHG emissions, year 2000



Data source: Climate Analysis Indicators Tool (CAIT) Version 4.0. (Washington, DC: World Resources Institute, 2007).

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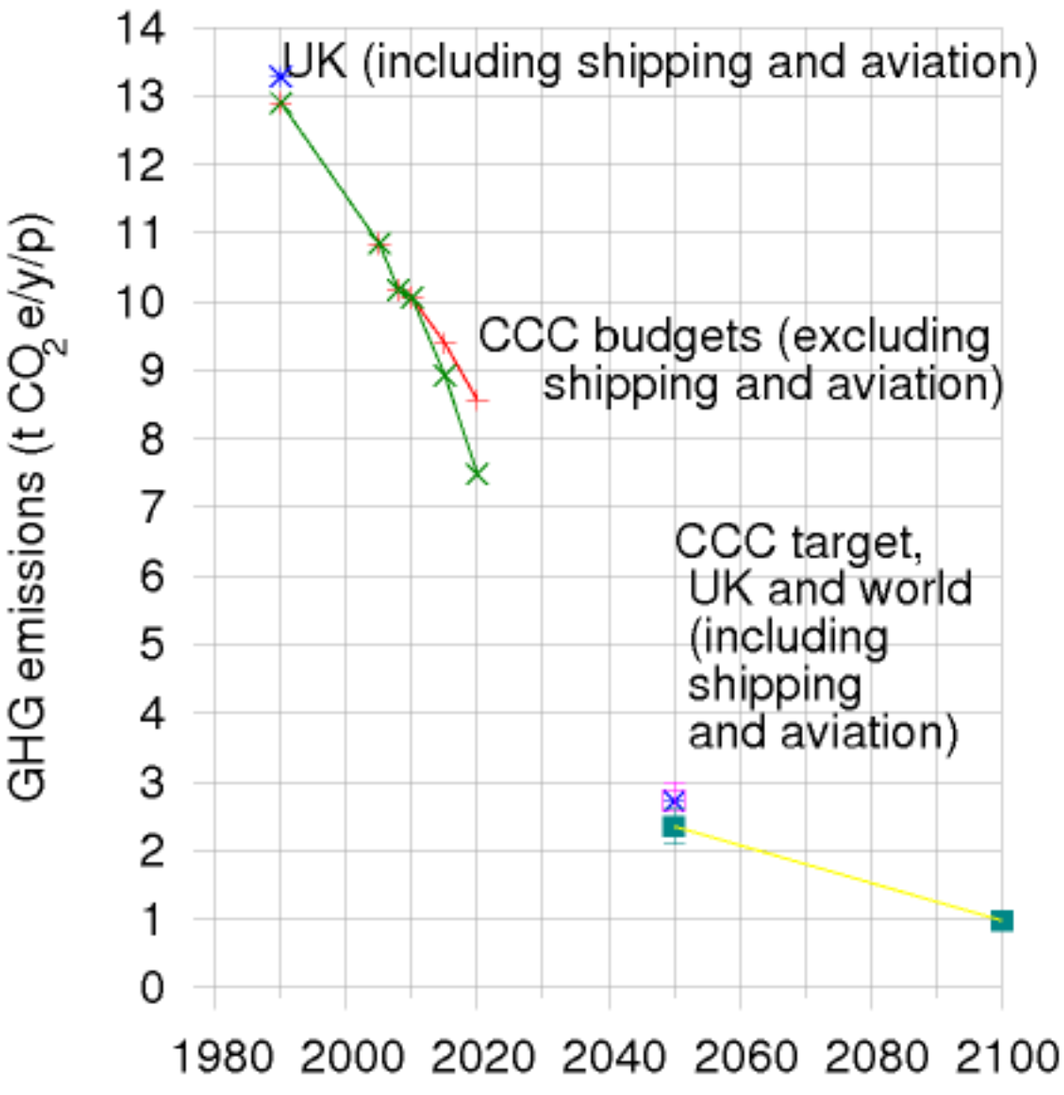
UK (including shipping and aviation)
CCC budgets (excluding shipping and aviation)
CCC target, UK and world (including shipping and aviation)
GHG emissions (t CO2e/y/p)
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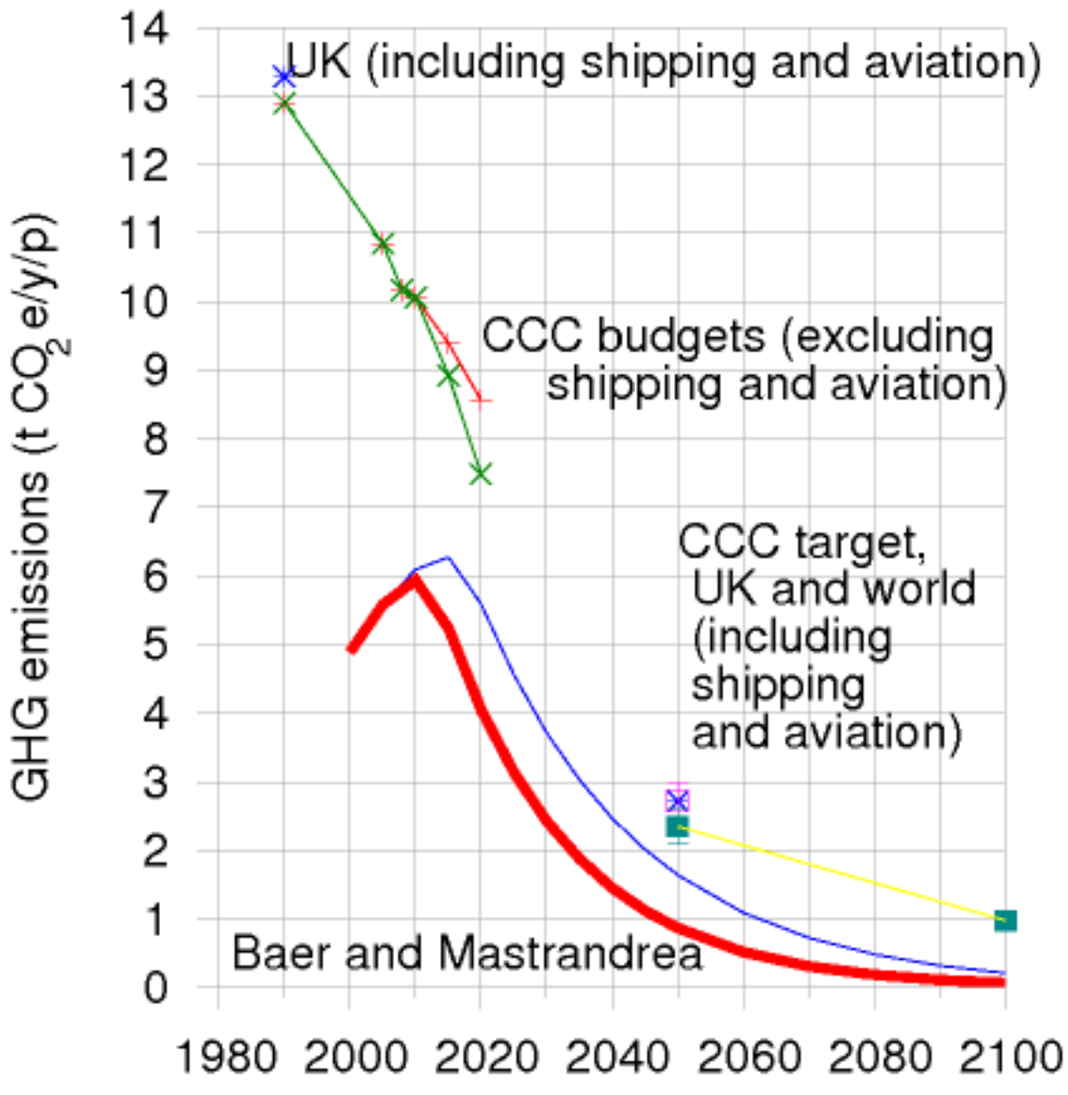
UK (including shipping and aviation)
CCC budgets (excluding shipping and aviation)
CCC target, UK and world (including shipping and aviation)
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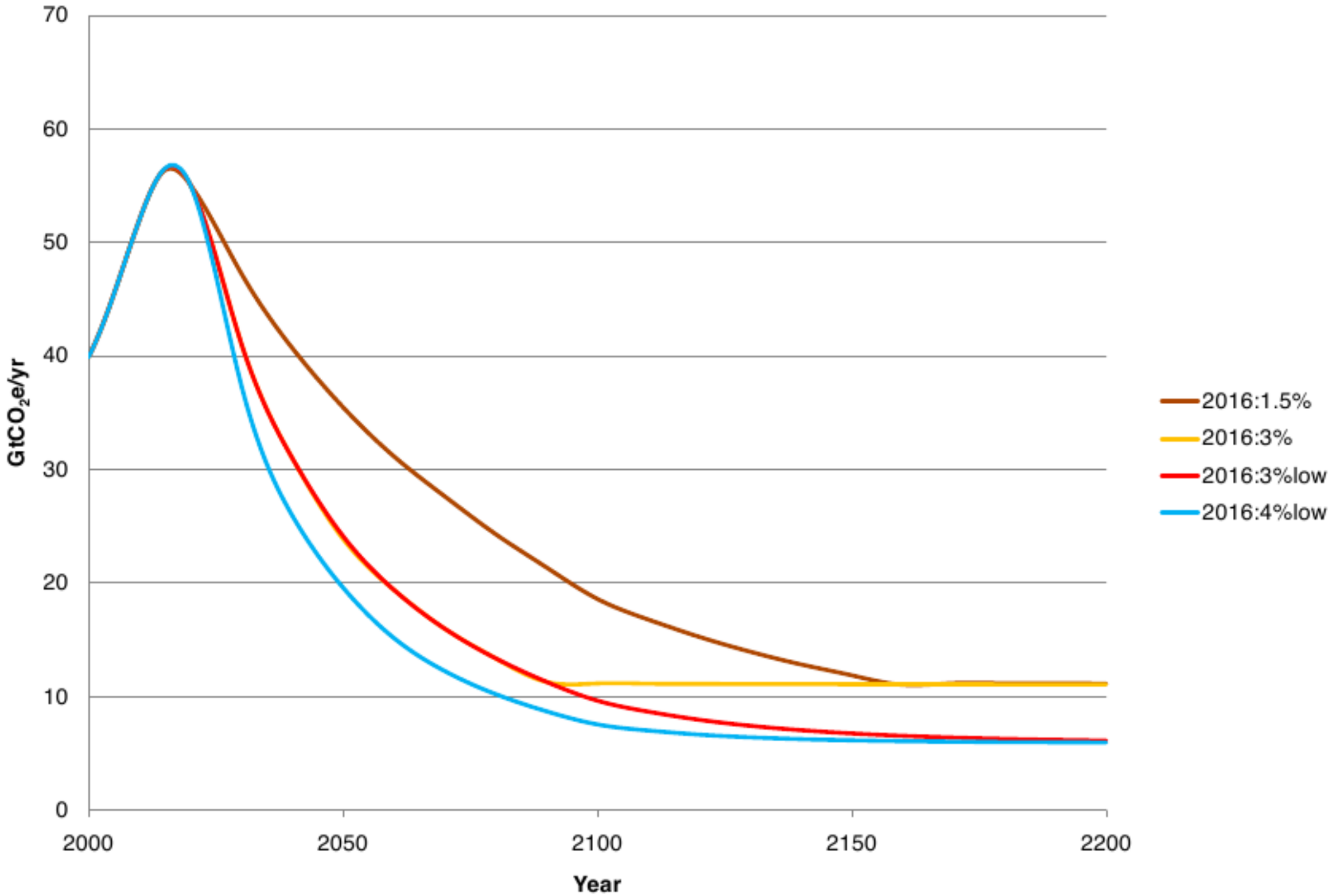
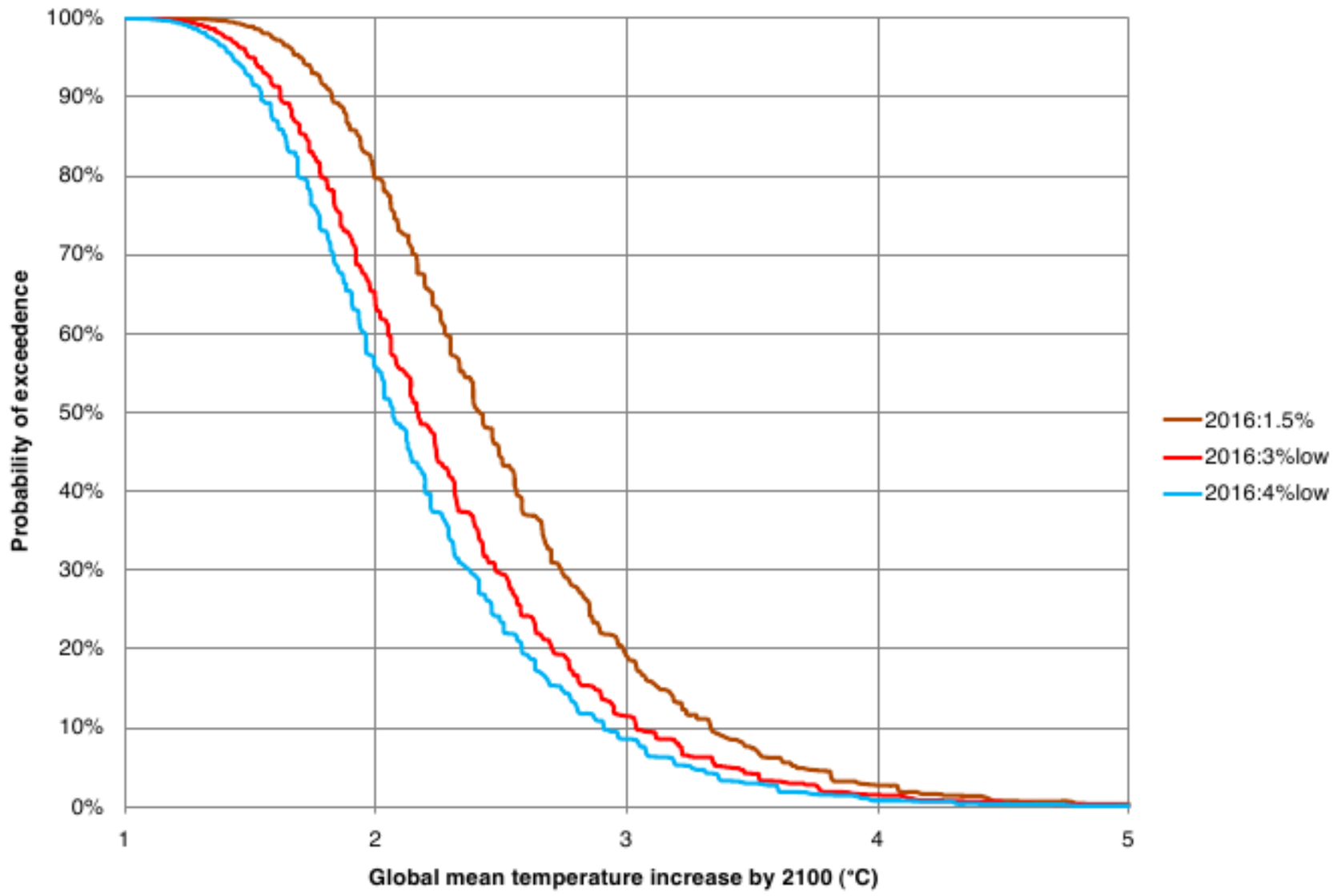
CCC's recommended trajectories ("3%")

Figure 1.7 Global emissions reduction trajectories peaking in 2016



Probability of dangerous climate change / 'extreme danger'

Figure 1.11 Probabilities of exceeding a given global mean temperature increase by 2100 for emissions trajectories peaking in 2016



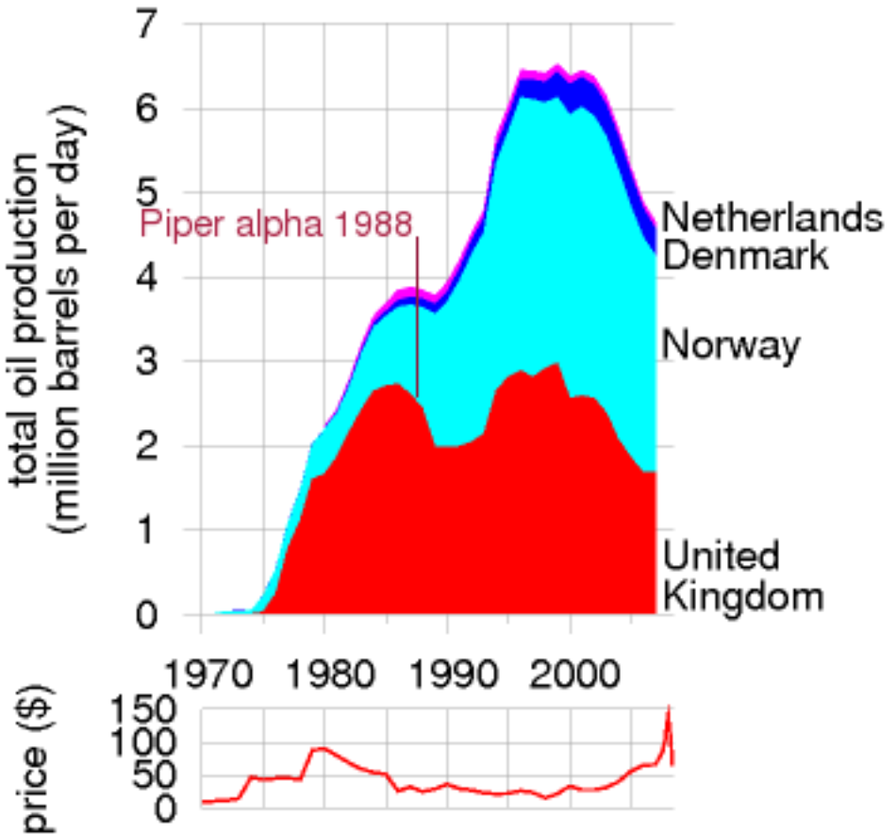
Note: Curves show the range of model outputs for given global temperature increase (relative to pre-industrial) in 2100, for the emissions trajectories peaking in 2016, given climate model parameters outlined in the Technical Appendix. Both 2016:3%low and 2016:3% give very similar probabilities at 2100.

'Security of supply'

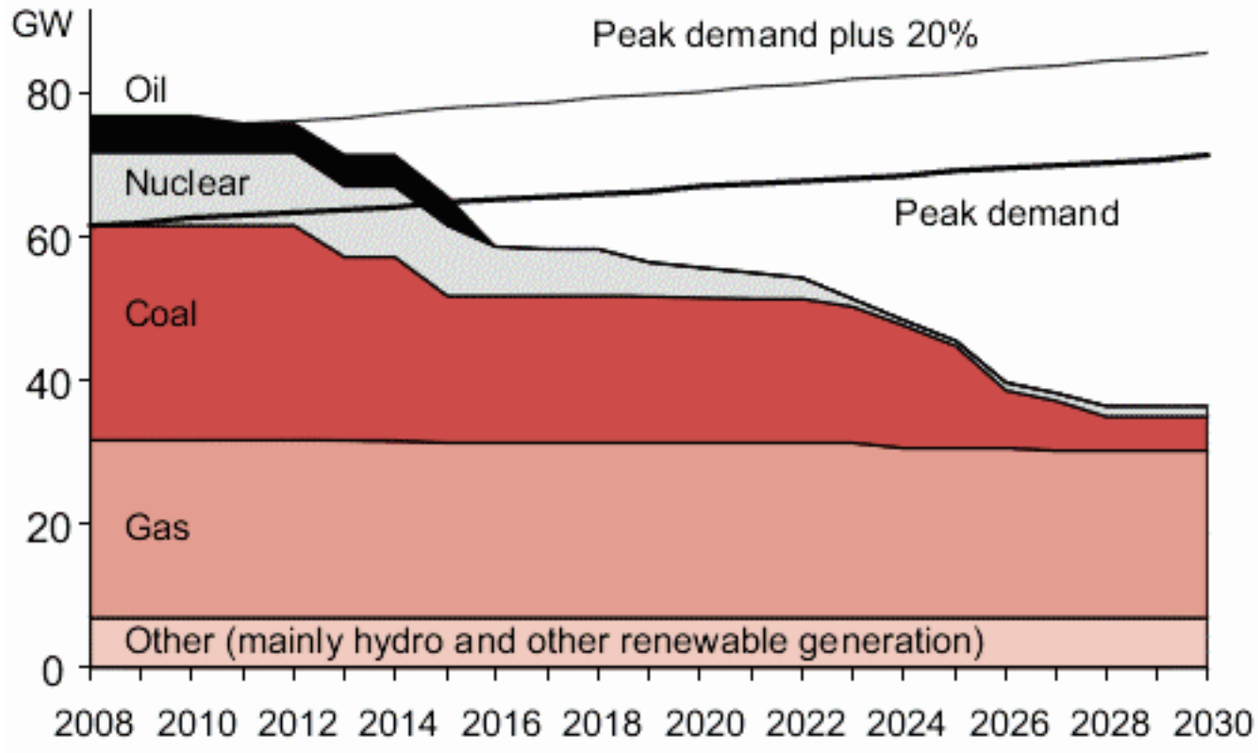
Magnus platform - delivers 5GW; 71,000 tonnes of steel

Photo by Terry Cavner

North Sea oil



The electricity gap



Source E.ON UK / House of Lords

We have an addiction to fossil fuels, and it's not sustainable

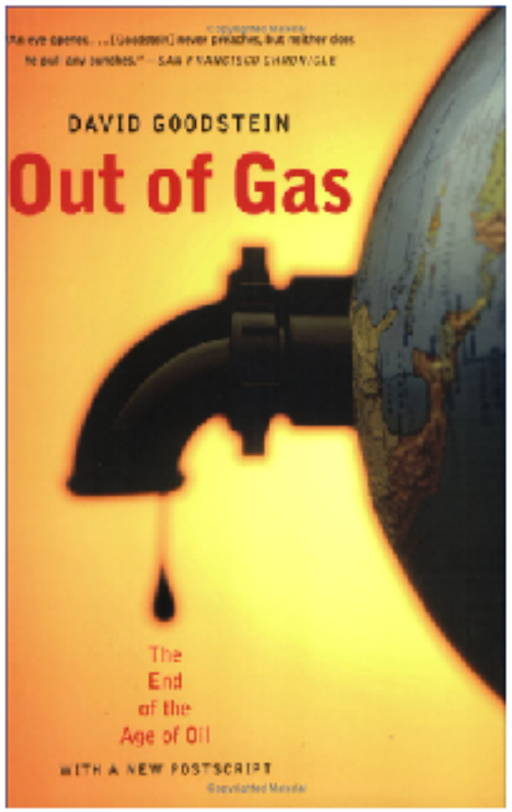


Photo by Terry Cavner

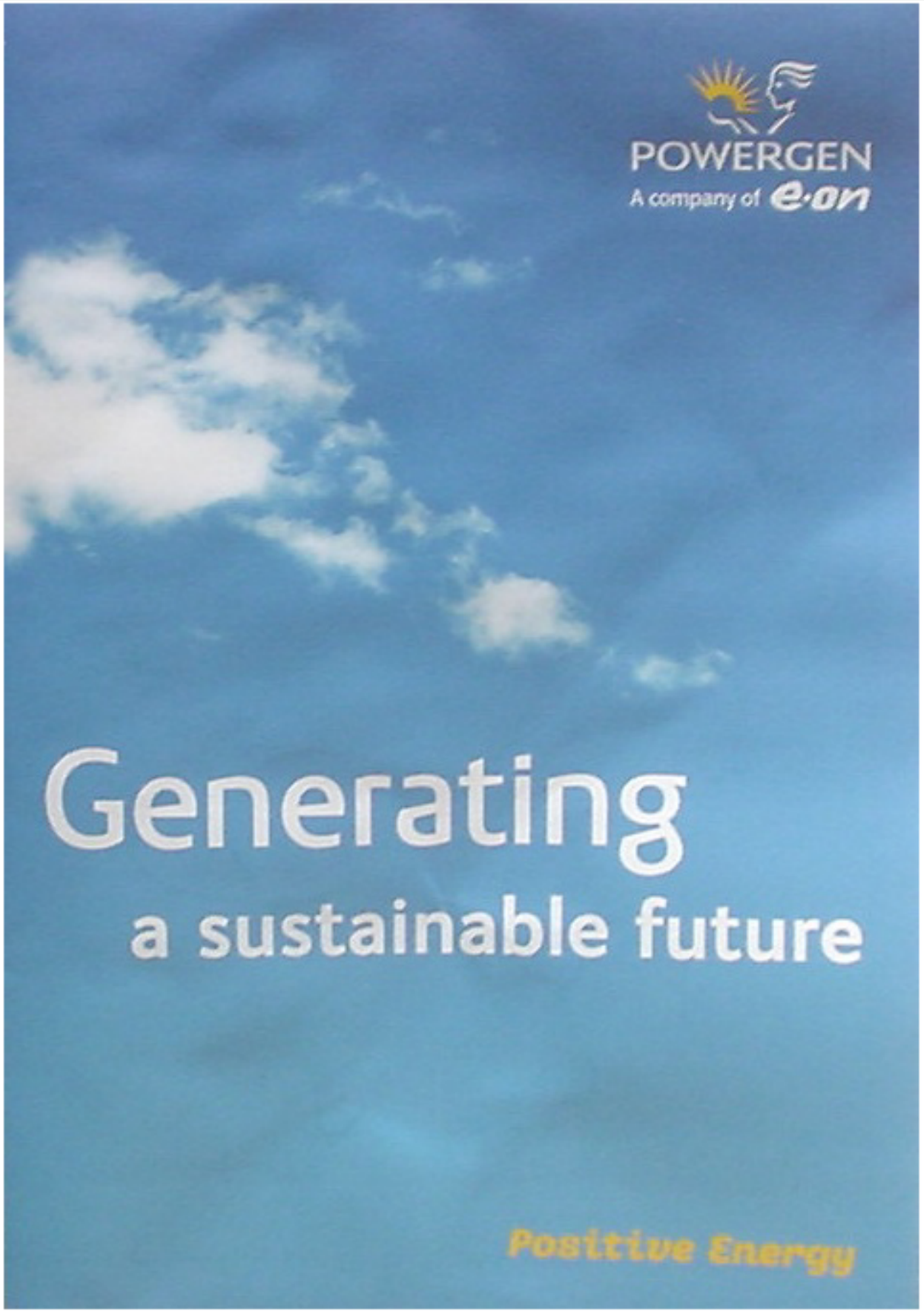
Something must be done!

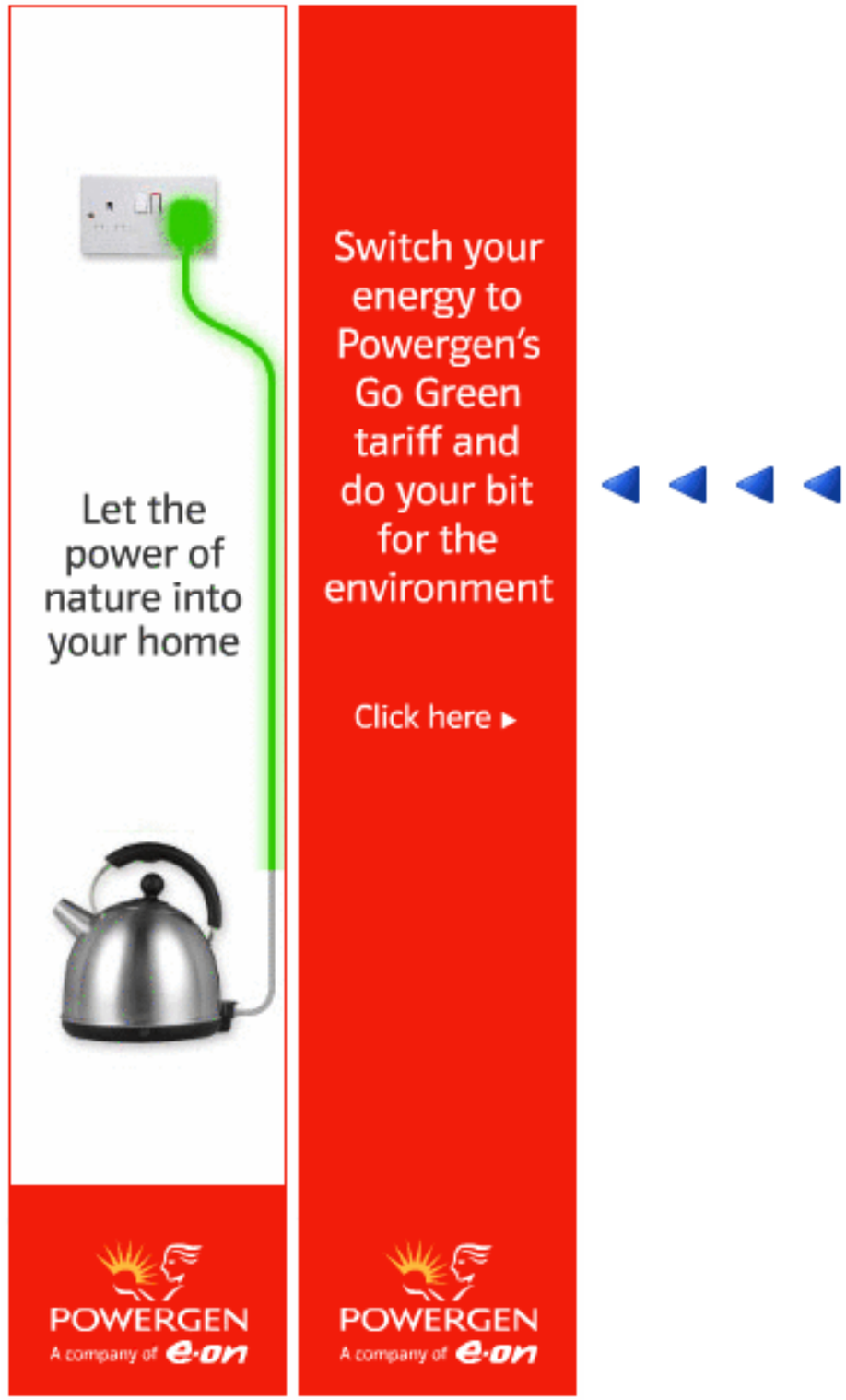
'Make a difference'

'Kinetic Plate' at a supermarket in Gloucester

The entrance road is a spur off a T-junction, therefore cars are accelerating across the kinetic plate.

'Do your bit'!





98% of Powergen's electricity is fossil; just 2% renewables

Advertising watchdog receives record complaints over corporate 'greenwash'

Will Ashley-Cantello
guardian.co.uk, Thursday May 1 2008 11.30 BST
Article history

The ASA upheld complaints against Shell's 'green' advert, which Friends of the Earth claimed misrepresented the environmental impact of the oil company's activities

Lexus ad banned over climate claims

Mark Sweney
guardian.co.uk, Wednesday September 24 2008 09.03 BST
Article history

Lexus ad: dismissed as misleading by the ASA. Click on magnifying glass in bottom-right corner to expand

A national press advertising campaign for a Lexus hybrid four-wheel drive car has been banned after it claimed it was "perfect for today's climate".

"Driving the world's first luxury hybrid SUV makes environmental, and economic, sense"

A larger

Environm
Corporate responsibil
living

Media
Advertising Authority · .

UK news

Related

Aug 13 2008
Shell reprimanded by ASA for 'misleading' advert

Jul 9 2008
BSkyB cleared over carbon-neutral ads

'Industry have done their bit'

The Times

The car industry has done its bit by making greener vehicles. Now we have to buy them, says **Sean O'Grady**

34mpg

- **219g/km**

ything.

HEAD

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The 2.4 Diesel is efficient and probably the best all-round choice, offering 34mpg overall. During the past few years, it has

trouble is, the R-Class is furiously expensive, with prices starting at more than £38,000.

Practically perfect: the Volvo XC90

Efficiency through technology

'a highly fuel-efficient aircraft'

- it burns 12 percent less fuel per passenger-km than a 747

'EfficientDynamics' reduces fuel consumption by up to 12%

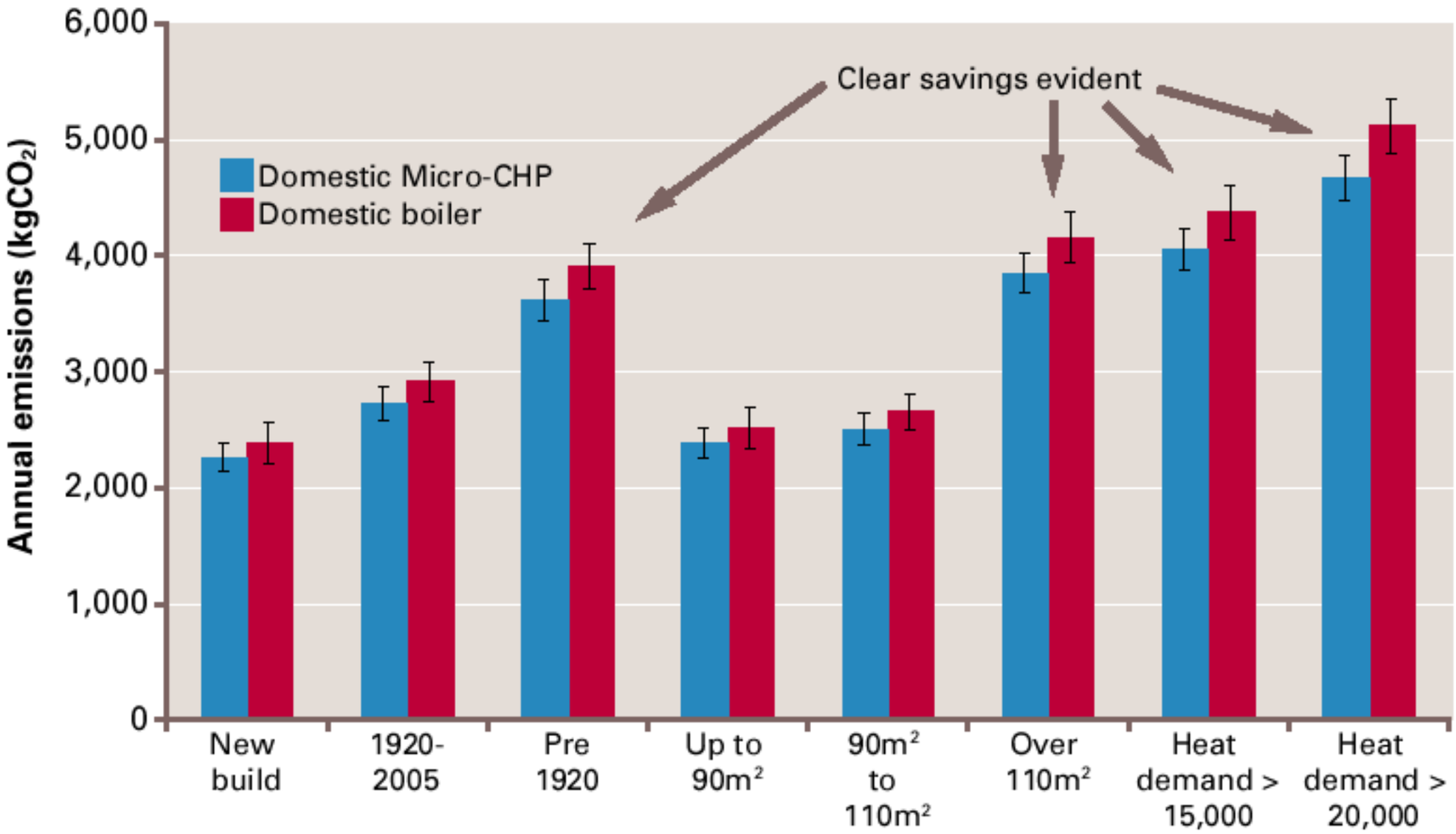
"The 180 kW straight six engine accelerates the 330d from 0 to 100 km/h in just 6.2 seconds, whilst combined fuel consumption is a miserly 6.8 l per 100 km"

Carbon Trust on Micro-CHP

(combined heat and power) (cogeneration)

"Micro-CHP is an emerging set of technologies with the potential to provide carbon savings in both commercial and domestic environments."

Figure 50 *Annual Micro-CHP and boiler emissions for cluster scenarios*



Solar bra brings conservation closer to the heart

Wed May 14, 2008 8:53pm IST

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anytime soon, said Triumph sp
Masuda, as "people usually ca
wearing clothes over it."

Green gifts

H2O multifunction clock

Incorporating the revolutionary and patented H20 water-powered battery, together with innovative use of conventional digital technology, the H20 Multifunction clock offers the user an environmental design solution for a product that is used in everyday life.

View larger image

H20 multifunction clock	£ 14.68	Buy

Simply rotate the clock to see a range of functions such as time, alarm, timer and temperature. For an endless source of energy, just add water. An electrochemical reaction between the electrodes and water produces electrical energy.

Product information

All components of the battery are recyclable. Each battery last approximately two years and needs to be filled with water

Something must be done!

(LoveHate) then Skip to 'Nuclear v wind' (page 60)
or Continue to Short Talk

A rough guide to sustainable energy

- No millions, billions, or trillions
- Make quantities comprehensible and comparable

- Do calculations per person, to one significant figure

- Energy unit: kWh

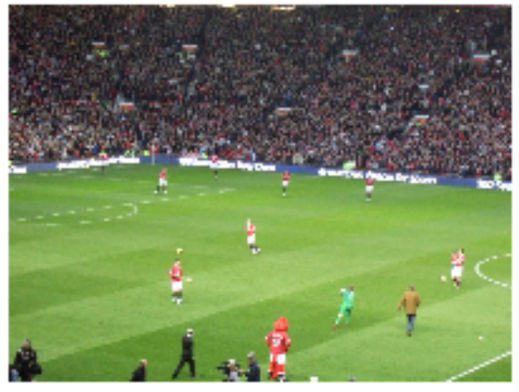
- Power: kWh per day

- Power per unit area: W per square metre

- Population density: square metres per person

$$\text{UK: } 4000 \text{ m}^2 \text{ per person}$$

- Examples
  - 20 mins of kettle - 1 kWh
  - food - 3 kWh / day(*)
  - bath - 5 kWh(*)
  - litre of petrol - 10 kWh
  - aluminium can - 0.6 kWh



Drive a car 100km...

80 kWh

ything.

HEAD

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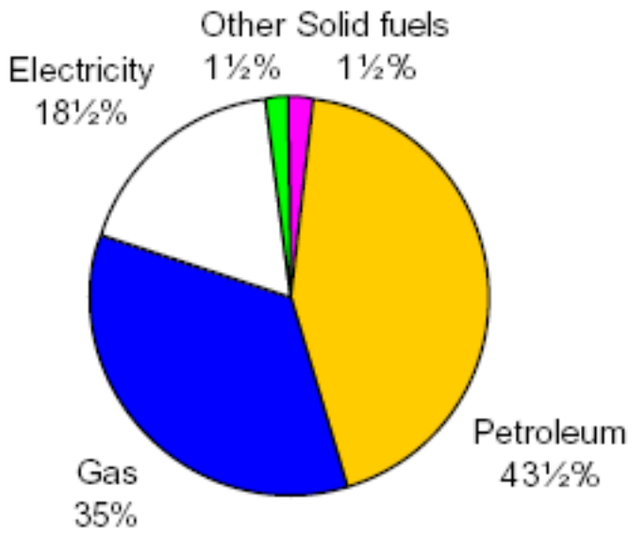
The 2.4 Diesel is efficient and probably the best all-round choice, offering 34mpg overall. During the past few years, it has

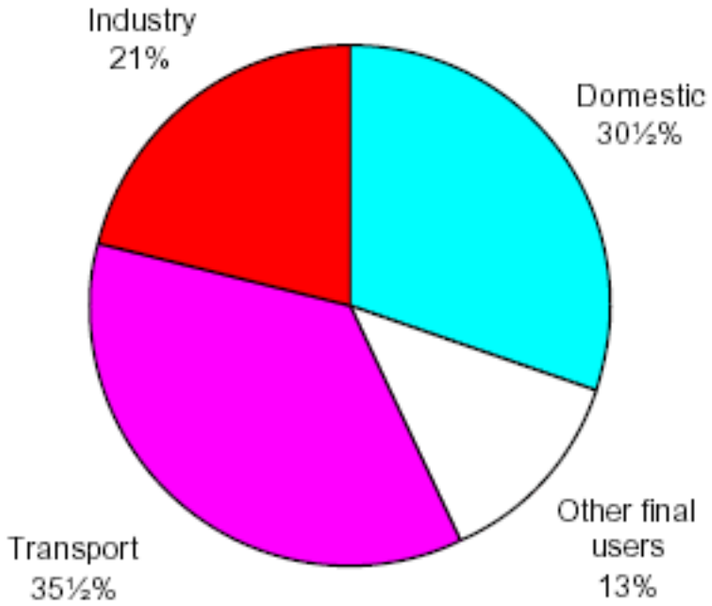
trouble is, the R-Class is furiously expensive, with prices starting at more than £38,000.

Practically perfect: the Volvo XC90

Average power consumption, UK: 125 kWh/d/p



2004



www.dti.gov.uk

125 kWh/day (Europe)

250 kWh/day (USA)

(Not including embodied energy in imports nor solar energy used by agriculture)

For CO_2 pollution, divide by 10:

100 kWh/day $\simeq$ 10 tonnes CO_2/yr

Wind

Current consumption

$v = 6\,\mathrm{m/s}$ (force 4)	
Wind farm	$2\,\mathrm{W/m^2}$ flat ground

UK: $4000\ \mathrm{m^2}$ per person

Put wind farms on 10% of the UK

- 400 square metres each

Current consumption: 125 kWh/d per person

Wind: **20 kWh/d**

...Twice as much windpower as the whole world;

50 x Denmark's

7 x Germany's

One 2-MW turbine for every 500 people

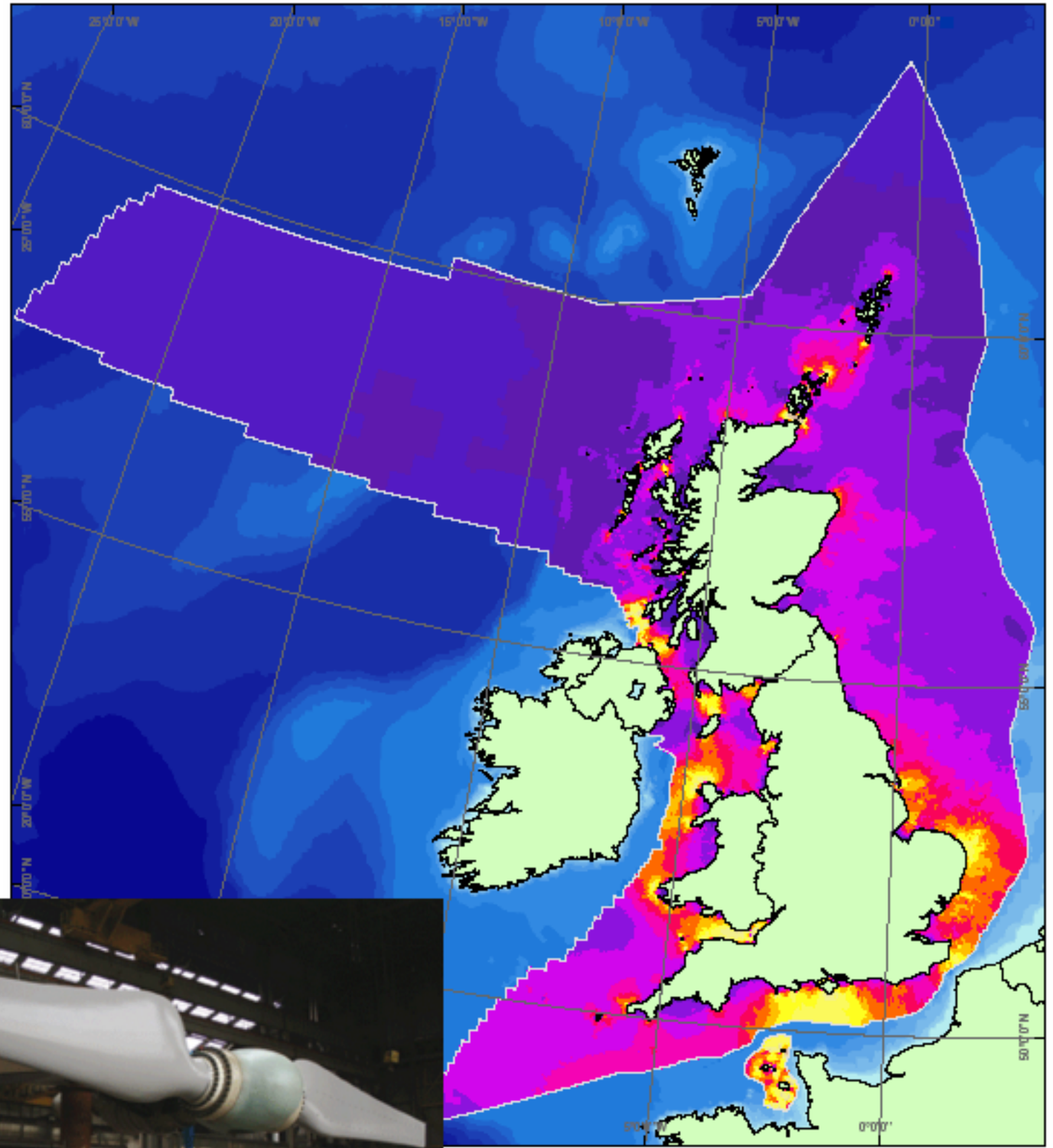
Roughly 100-fold increase over today's UK wind

Renewables are diffuse

Power per unit land area

Wind	$2\,\mathrm{W/m^2}$
Offshore wind	$3\,\mathrm{W/m^2}$
Tidal pools	$3\,\mathrm{W/m^2}$
Tidal stream	$8\,\mathrm{W/m^2}$
Solar PV panels	$5\text{–}20\,\mathrm{W/m^2}$
Plants	$0.5\,\mathrm{W/m^2}$
Solar chimney (Spain)	$0.1\,\mathrm{W/m^2}$
Concentrating solar power (desert)	$15\text{–}20\,\mathrm{W/m^2}$
Ocean thermal	$5\,\mathrm{W/m^2}$
Rain-water (highlands)	$0.24\,\mathrm{W/m^2}$
Rain-water (lowlands)	$0.02\,\mathrm{W/m^2}$

- To make a difference, renewable facilities have to be country-sized



marineturbines.com

All renewables are diffuse

Power per unit land area	
Wind	$2\,\mathrm{W/m^2}$
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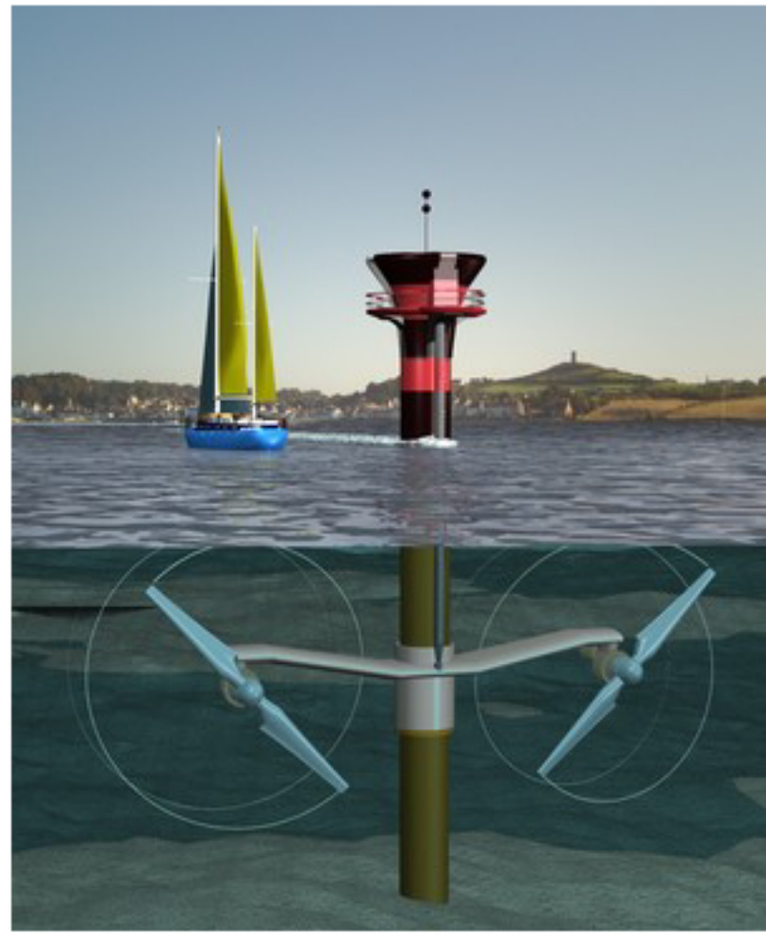

marineturbines.com

- To make a difference, renewable facilities have to be country-sized

Bavaria Solar Park: $5\,\mathrm{W/m^2}$; this picture shows $0.7\,\mathrm{MW}$ (average)

All renewables are diffuse

Power per unit la	
Wind	
Offshore wind	
Tidal pools	
Tidal stream	
Solar PV panels	
Plants	
Solar chimney (Spain)	
Concentrating solar power (des	
Ocean thermal	3 W/m²
Rain-water (highlands)	$0.24\,\mathrm{W/m^2}$
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- To make a difference, renewable facilities have to be country-sized

Renewables are diffuse

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Rain-water (highlands)	$0.24\,\mathrm{W/m^2}$
Rain-water (lowlands)	$0.02\,\mathrm{W/m^2}$

- To make a difference, renewable facilities have to be country-sized

Block

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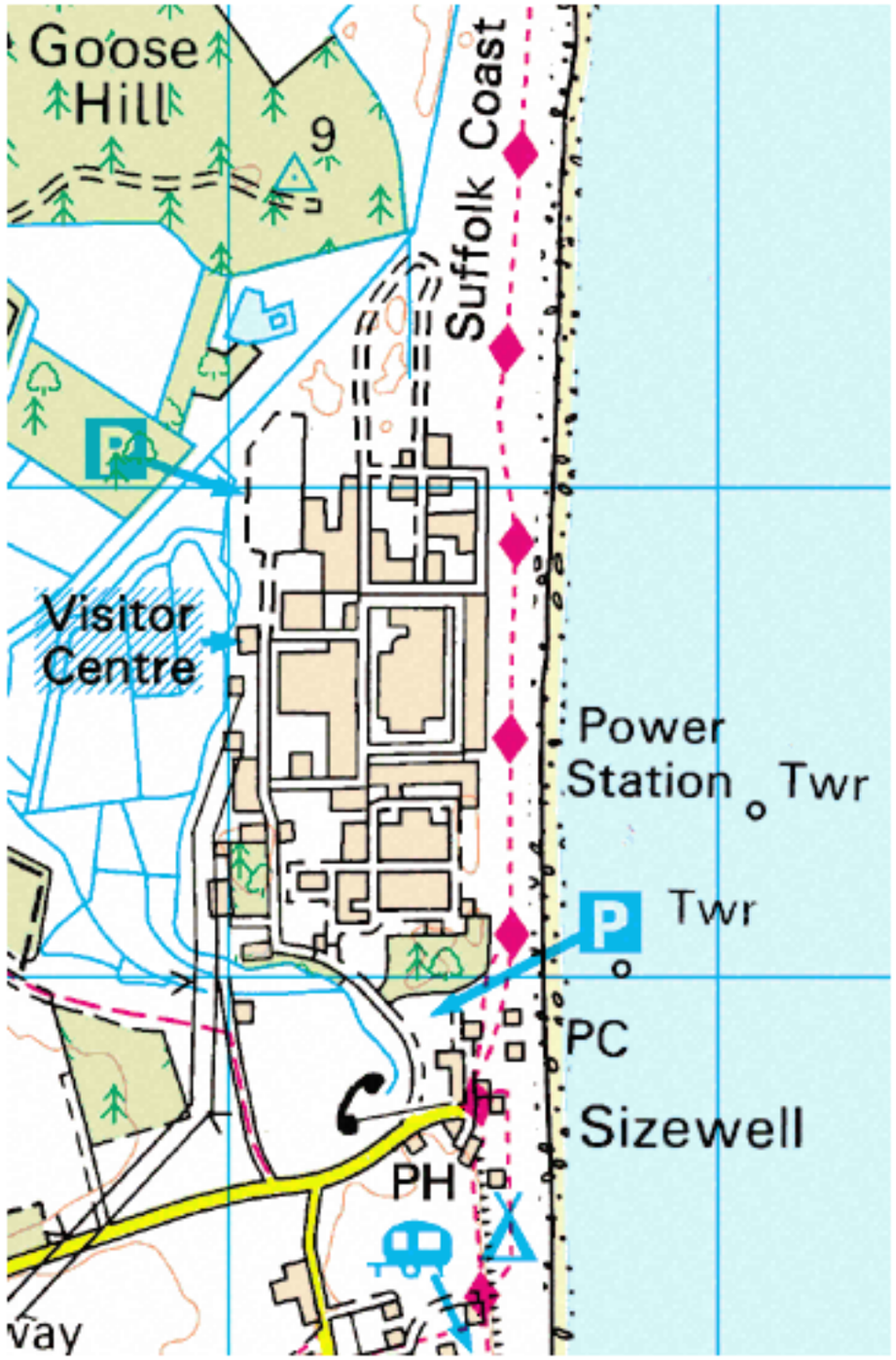
No green light for Severn barrage

Last modified: 01 October 2007

Europe's most dynamic estuary will be destroyed by the construction of a barrage across the Severn while other less striking measures would cost less and could do more to cut carbon emissions.

"other less striking measures"?

To make a difference, renewable facilities have to be country-sized



Nuclear	
Fission	$1000\,\mathrm{W/m^2}$













Current consumption: 125 kWh/d per person

We can't live on our own renewables

- at least, not as we currently live

Geothermal: ~~1 kWh/d~~

Tide: **11 kWh/d**

Wave: **4 kWh/d**

Shallow offshore wind: **16 kWh/d**

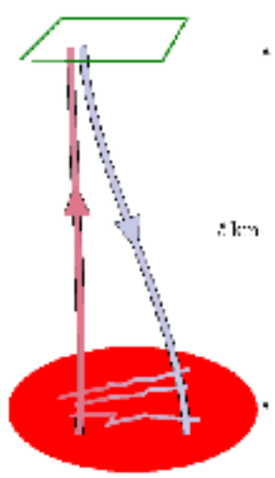
Hydro: 1.5 kWh/d

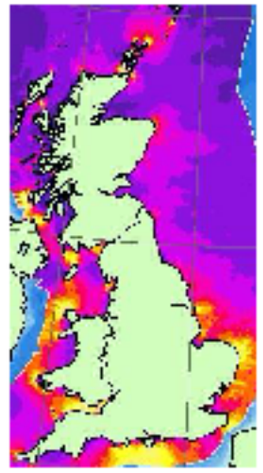
Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**

PV, 10 m^2/p: **5**

Solar heating: **13 kWh/d**

Wind: **20 kWh/d**










www.withouthotair.com

Skip to page 109

- Optional extra on wind power per unit area: page 68

Nuclear versus Wind

"if we're going to cut greenhouse gases by 60% by 2050 there is no other possible way of doing that except through renewables".

Michael Meacher

former Environment Minister

"anybody who is relying upon renewables to fill the energy gap is living in an utter dream world and is, in my view, an enemy of the people."

Sir Bernard Ingham

former civil servant, Chief Press Secretary, Head of the Government Information Service

'We have a *huge* amount of wave and wind'.

'Nuclear is a money pit'.

Ann Leslie

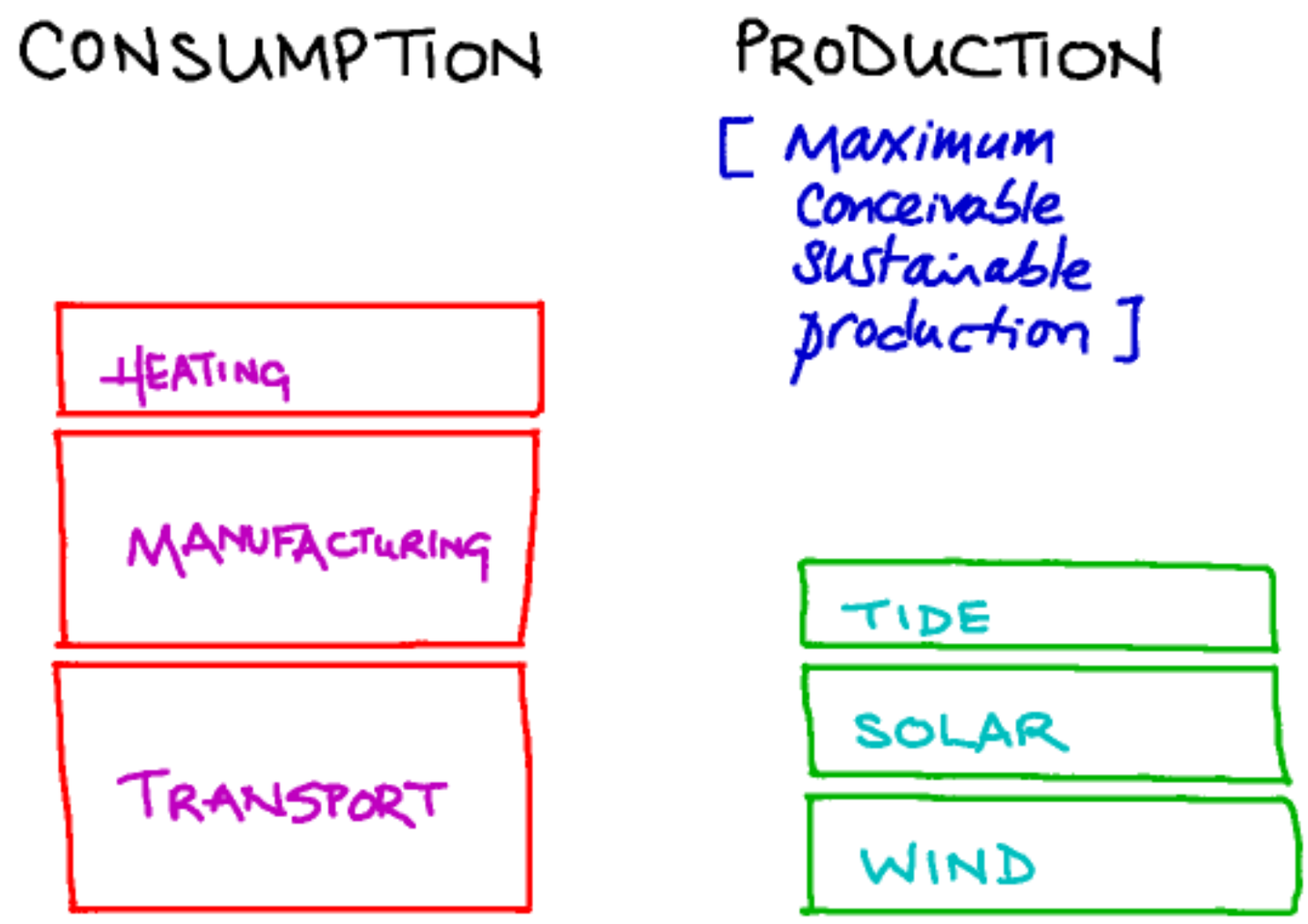
journalist

We need numbers, not adjectives

- Part I: Numbers, not adjectives
  - Could a country like Britain live on its own renewables?
- Part II: Energy plans that add up

Part I: Numbers, not adjectives

- Ignore economic, social, + environmental constraints



Choose good units

- No millions, billions, or trillions
- Make quantities comprehensible and comparable

- Do calculations per person, to one significant figure

- Energy unit: kWh

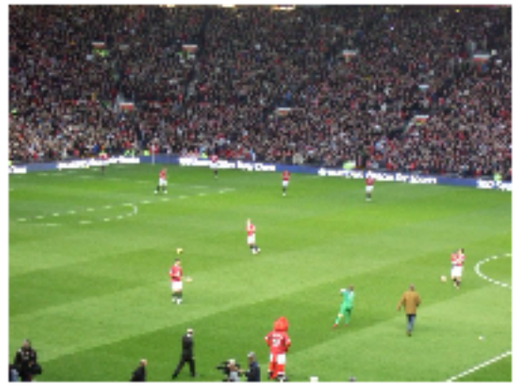
- Power unit: kWh per day

- Fluxes: W per square metre

- Population density: square metres per person

UK: $4000\ \mathrm{m}^2$ per person

- Examples
  - 20 mins of kettle - 1 kWh
  - food - 3 kWh / day(*)
  - bath - 5 kWh(*)
  - litre of petrol - 10 kWh
  - aluminium can - 0.6 kWh



Cars

$$\begin{aligned}
\text{Energy used per day} &= \frac{\text{Distance travelled per day}}{\text{Distance per unit of fuel}} \times \text{Energy per unit of fuel} \\
&= \frac{50\,\text{km/day}}{12\,\text{km/litre}} \times 10\,\text{kWh/litre} \\
&\simeq 40\,\text{kWh/day}.
\end{aligned}$$

Car:
40 kWh/d

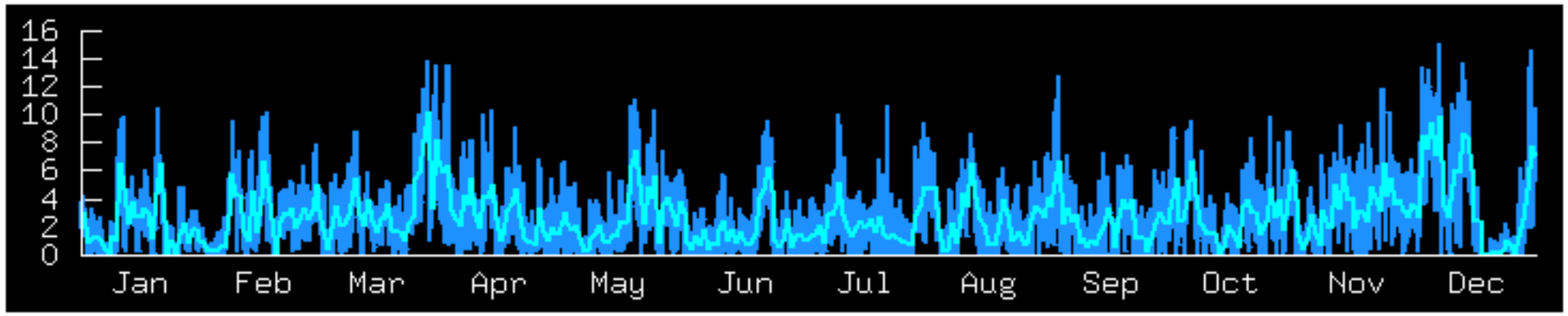
33 miles per UK gallon

40 kWh is not an average figure for UK, but a plausible value for an ordinary car-lover

f

Wind

Wind



Windspeeds Cambridge 2006 (m/s) Half-hourly and daily

Wind

$v = 6\,\mathrm{m/s}$ (force 4)
Wind farm $2\,\mathrm{W/m^2}$ flat ground

UK: 4000 m^2 per person

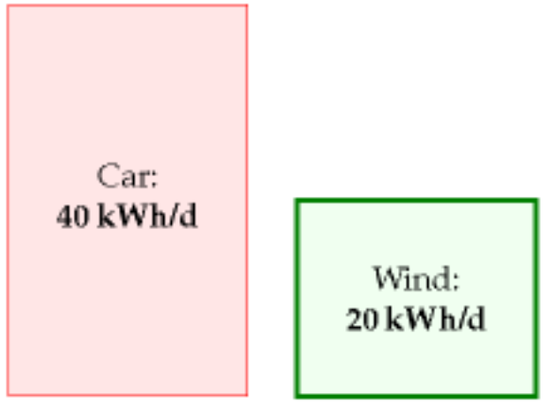
Put wind farms on 10% of the country

- 400 square metres each

...Twice as much windpower as the whole world;

50 x Denmark's

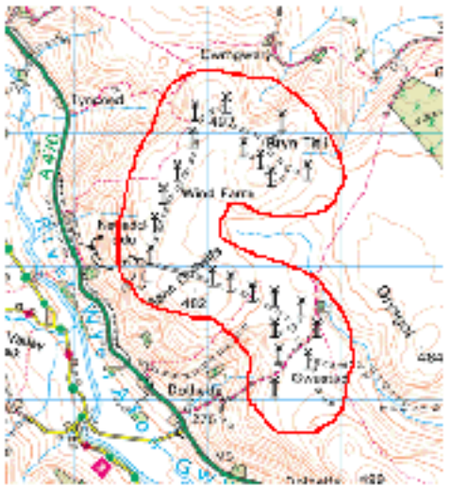
7 x Germany's

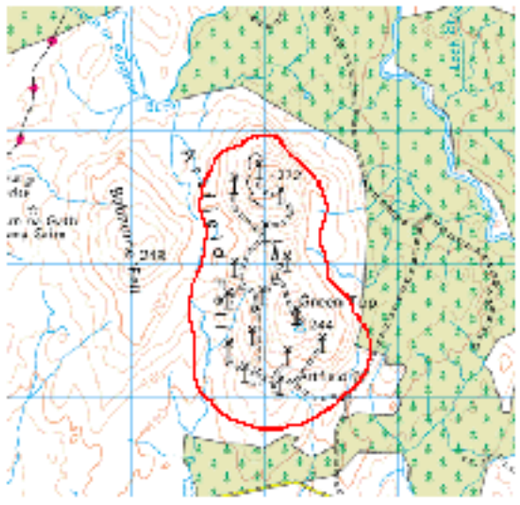


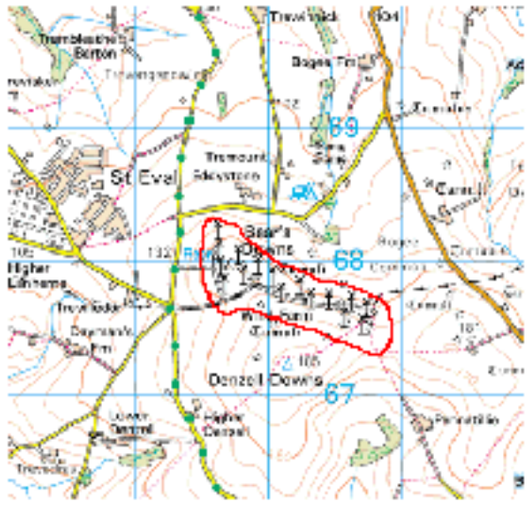
9f to go to flight

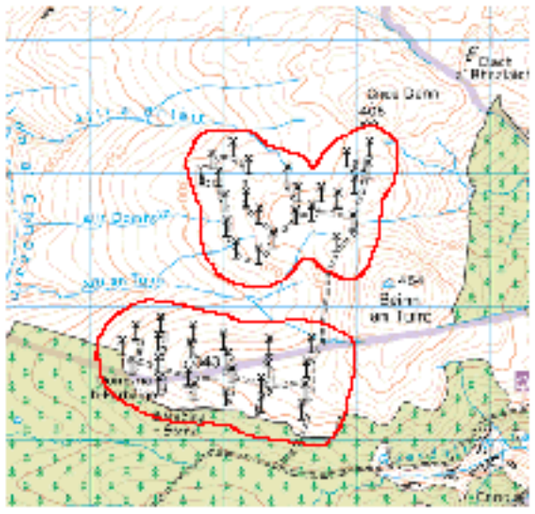
1f for wind farm survey

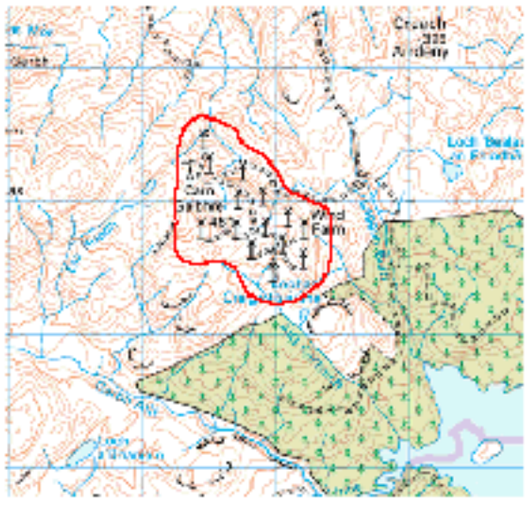
British wind farm survey

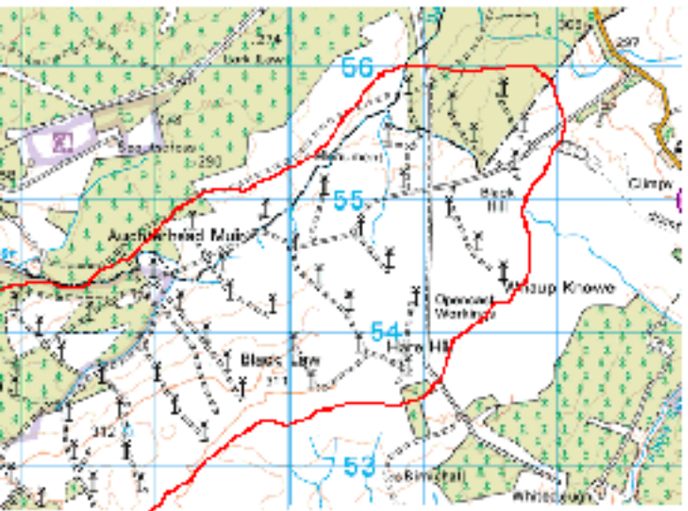


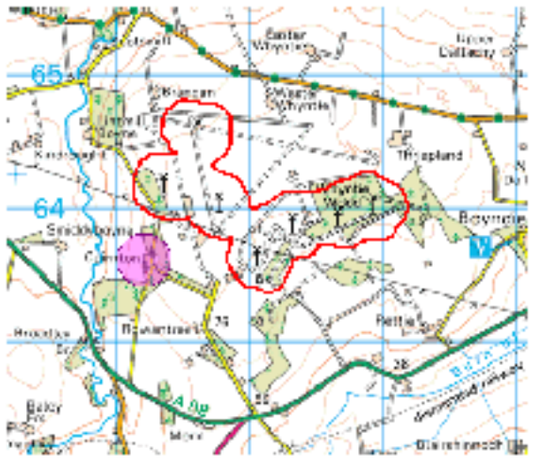


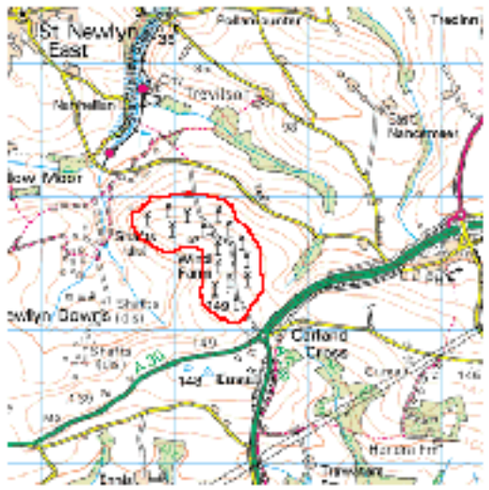


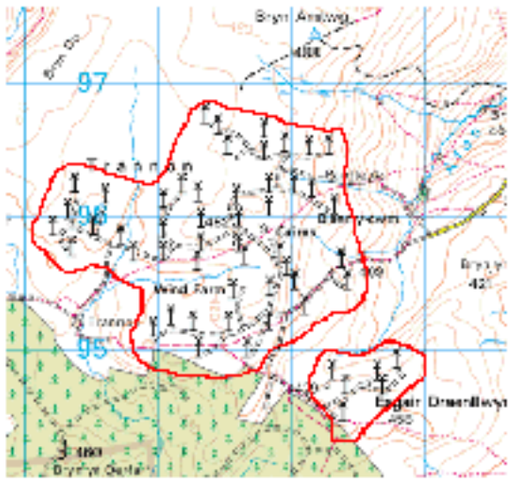


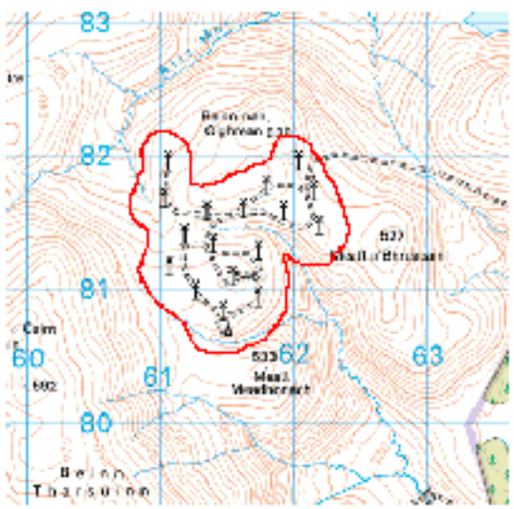


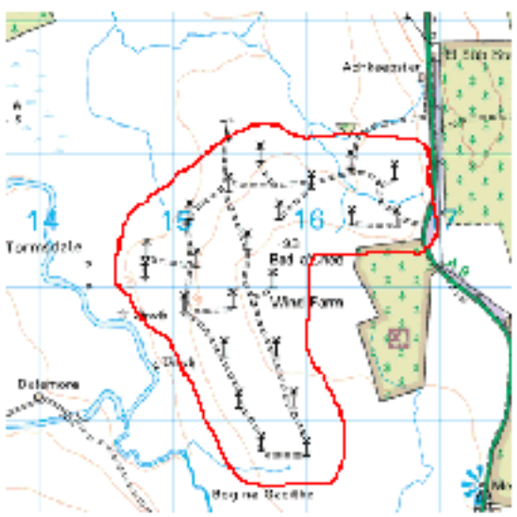


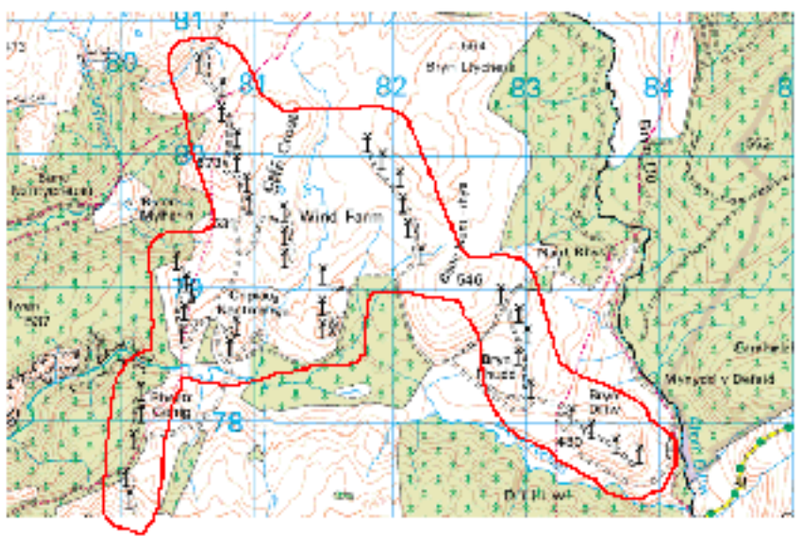




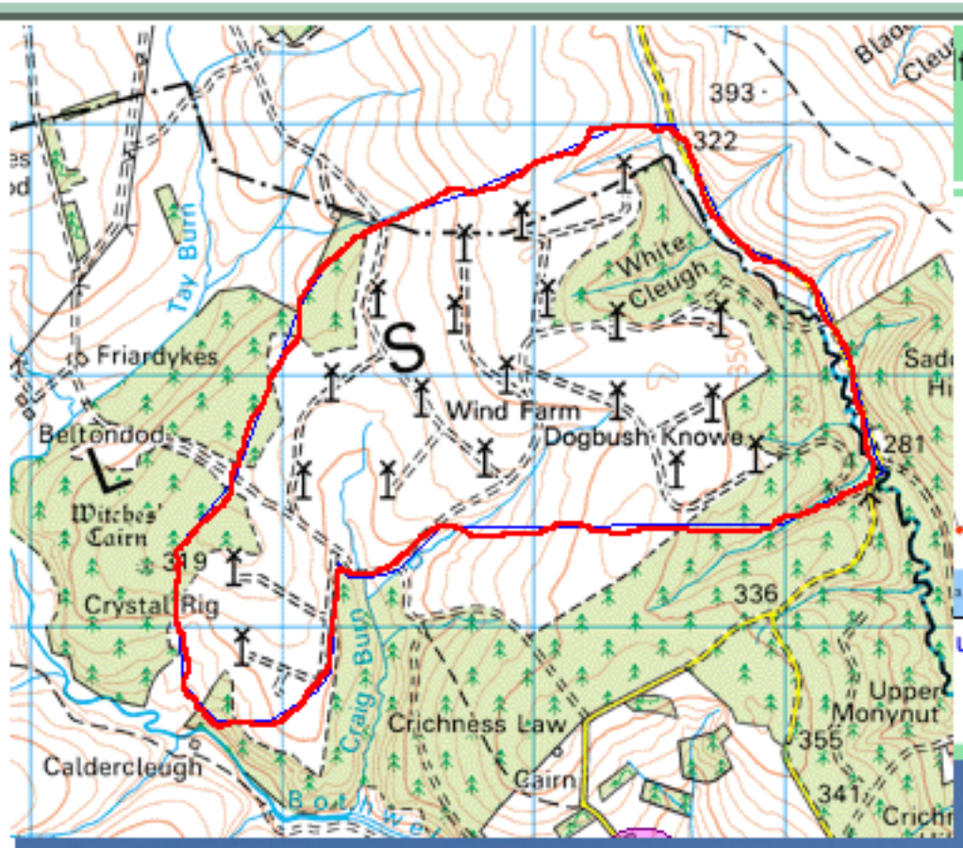




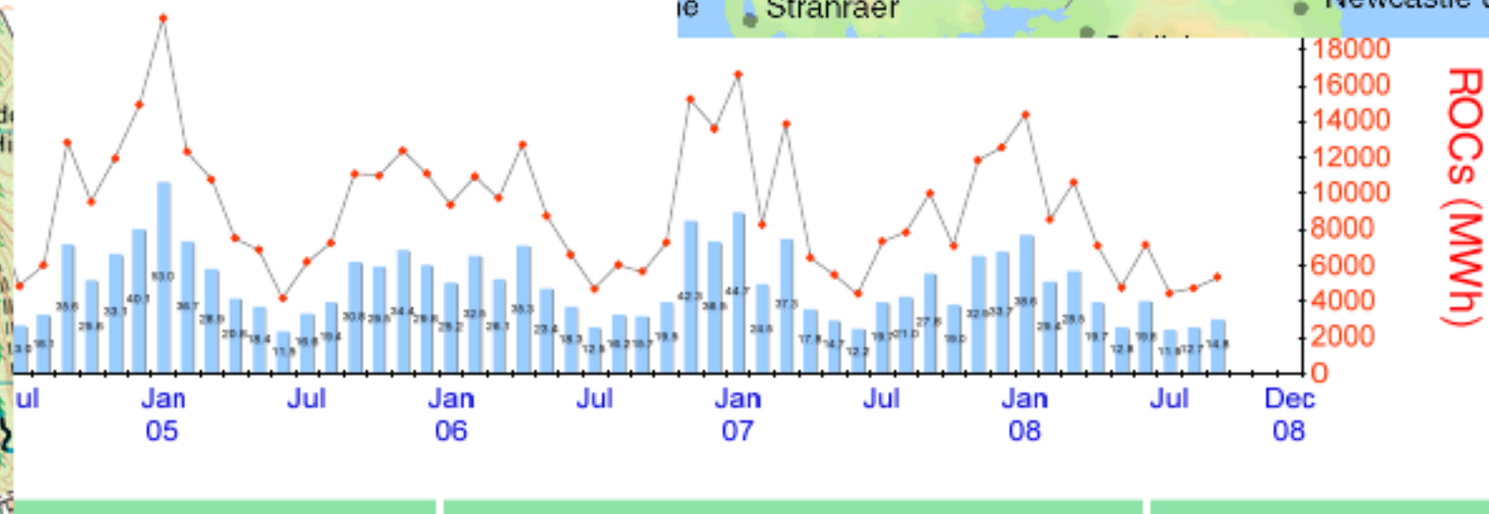




Crystal Rig Windfarm



farm



ry

Annual ROCs (MWh)	Annual LF (%)
0	
2,941	
75,312	17.2
120,234	27.5
110,414	25.2
111,576	25.5

Turbine Summary

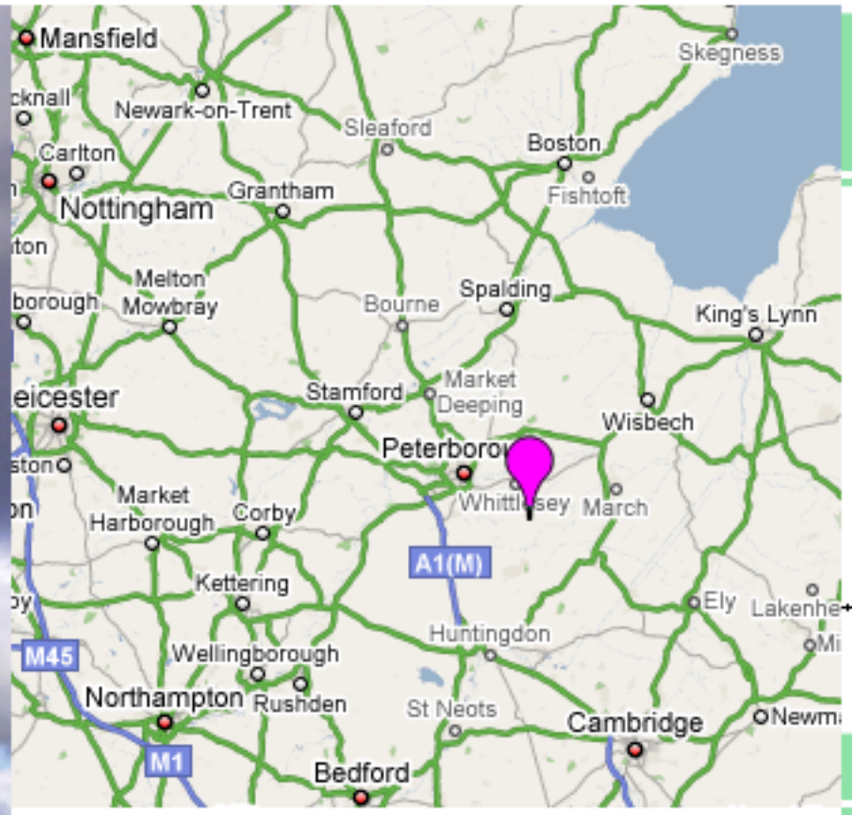
Wind turbine model	Nordex
No of turbines	20
Size of turbine (kW)	2,500
Rotor diameter (m)	80
Hub height (m)	60

Average 13 MW from 3.5 km^2

Power per unit area: 3.7 W/m^2

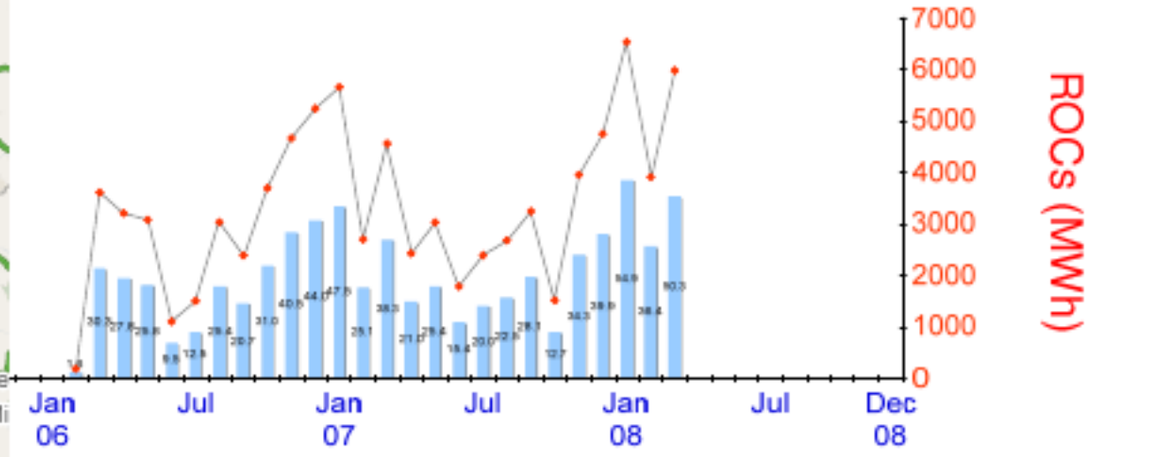
82m diameter

Glass Moor, Peterborough, Cambridgeshire



R.O. ID R00159RQEN

Current TIGC (kW) 16,000



Annual Summary

Year	Annual TIGC (kW)	Annual ROCs (MWh)	Annual LF (%)
2002	0	0	
2003	0	0	
2004	0	0	
2005	0	0	
2006	16,000	31,645	
2007	16,000	38,635	27.6

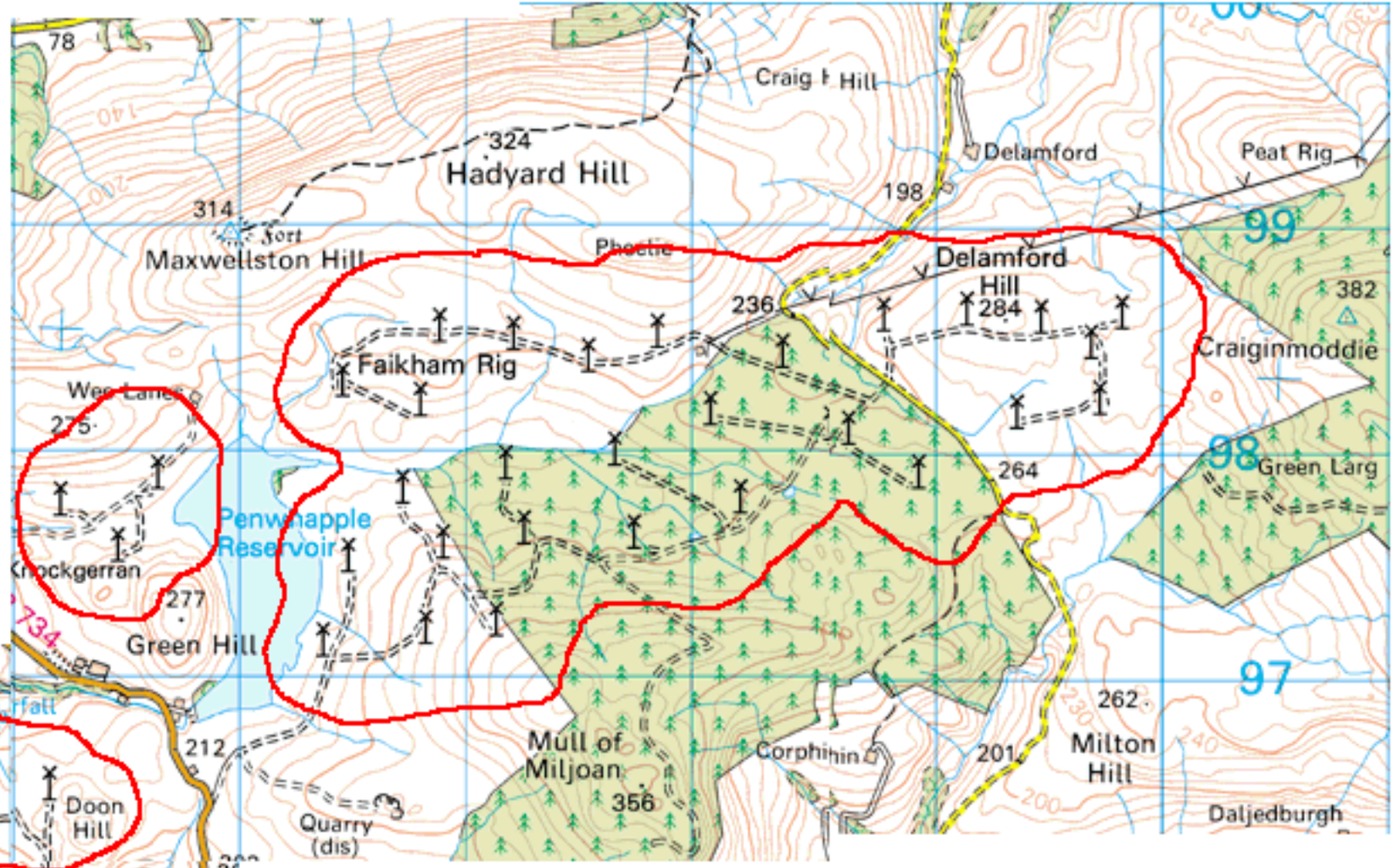
Turbine Summary

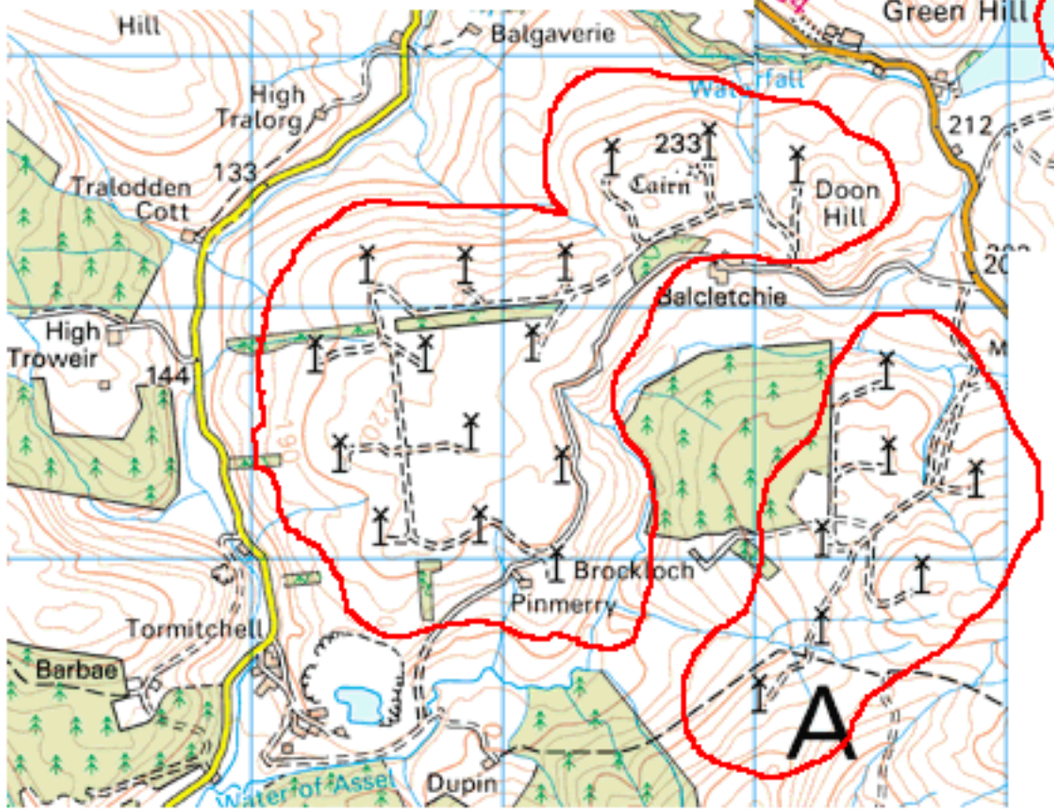
Wind turbine model	REPower
No of turbines	8
Size of turbine (kW)	2,000
Rotor diameter (m)	82
Hub height (m)	59

Average 4.4 MW from 2 km^2

Power per unit area: 2.2 W/m^2

Hadyard Hill





Average 29 MW from 10.2 km^2

Power per unit area: 2.8 W/m^2

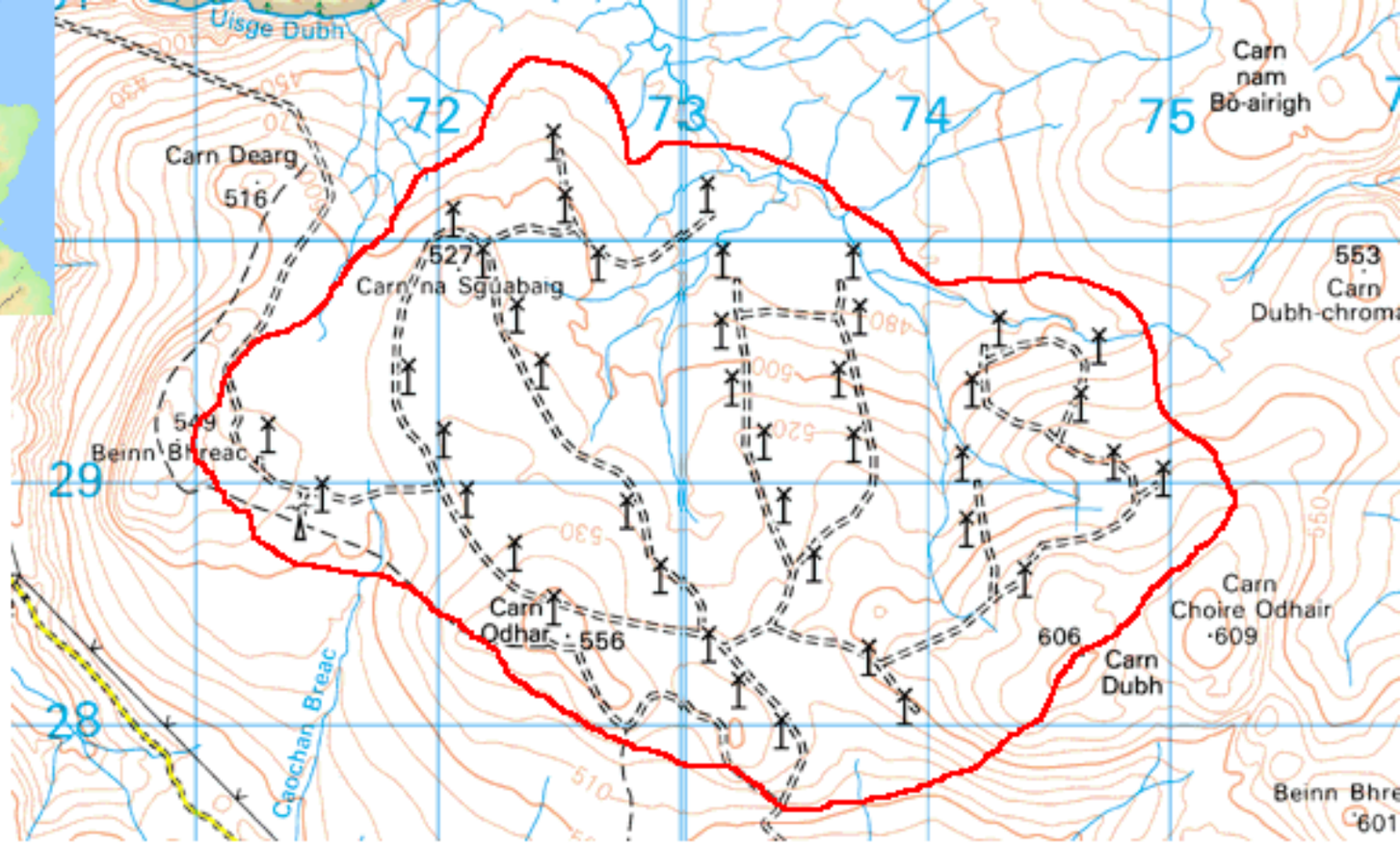
Farr windfarm

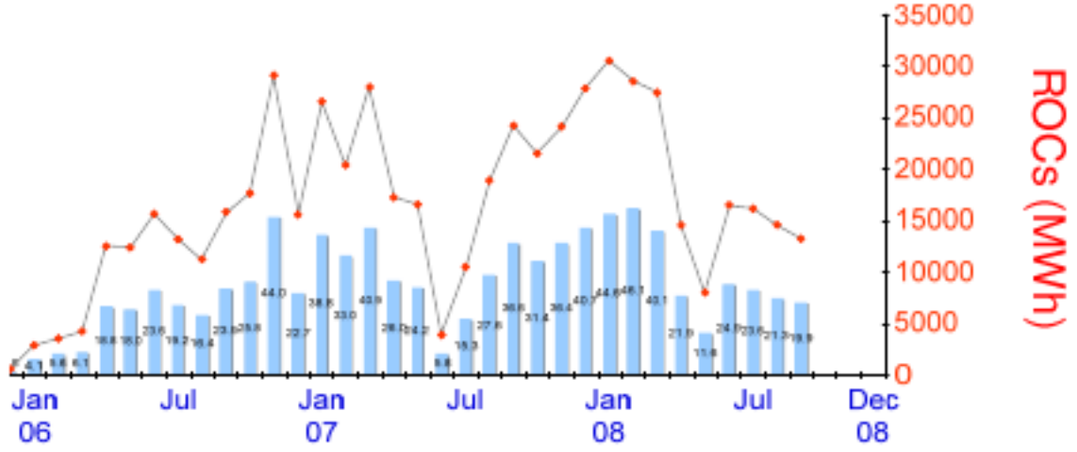
92MW Capacity

Average 27 MW from 8 km^2

Power per unit area: 3.4 W/m^2

Load factor 29.7%



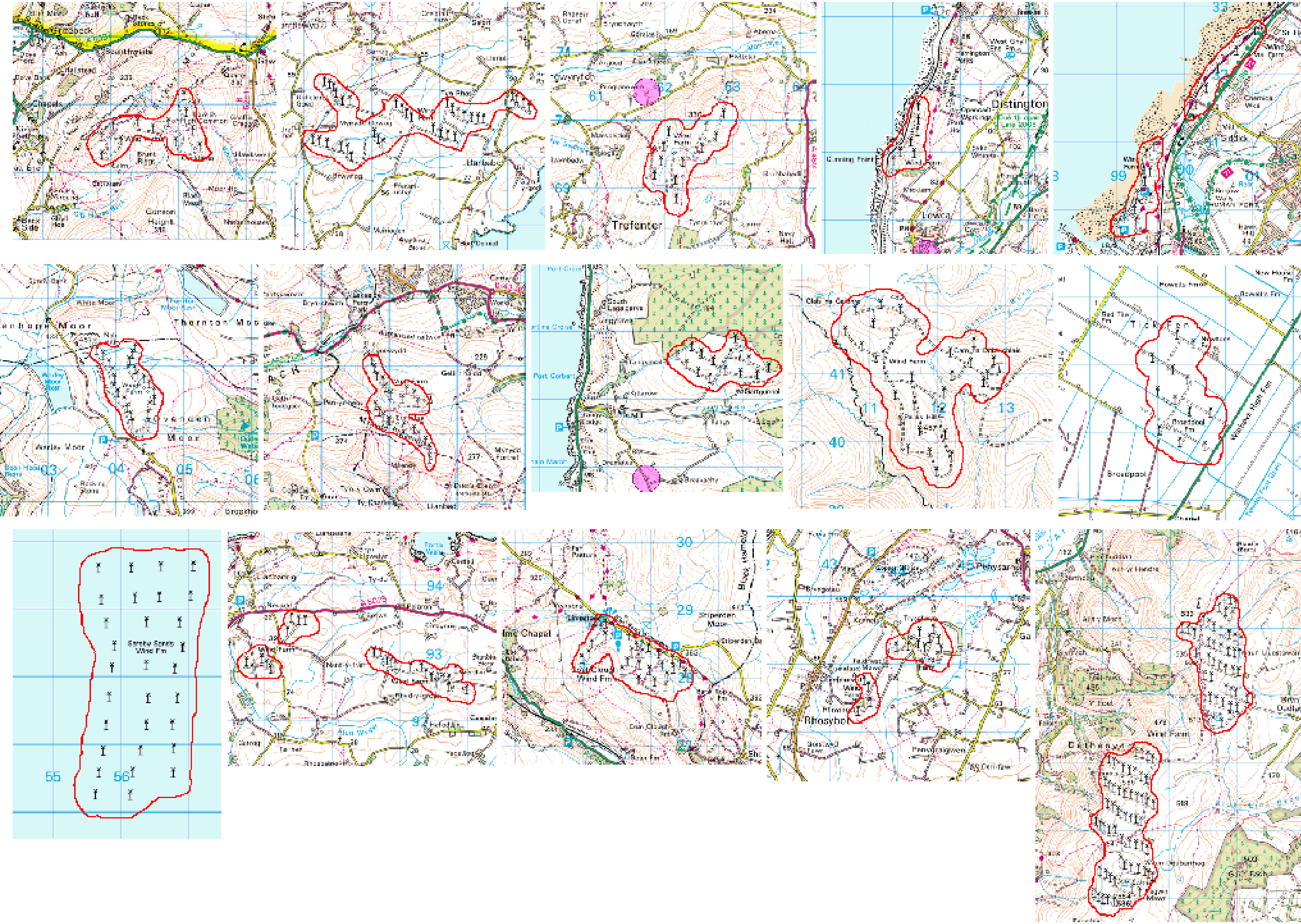


Annual Summary

Year	Annual TIGC (kW)	Annual ROCs (MWh)	Annual LF (%)
2002	92,000	0	
2003	92,000	0	
2004	92,000	0	
2005	92,000	519	
2006	92,000	153,419	19.0
2007	92,000	239,520	29.7

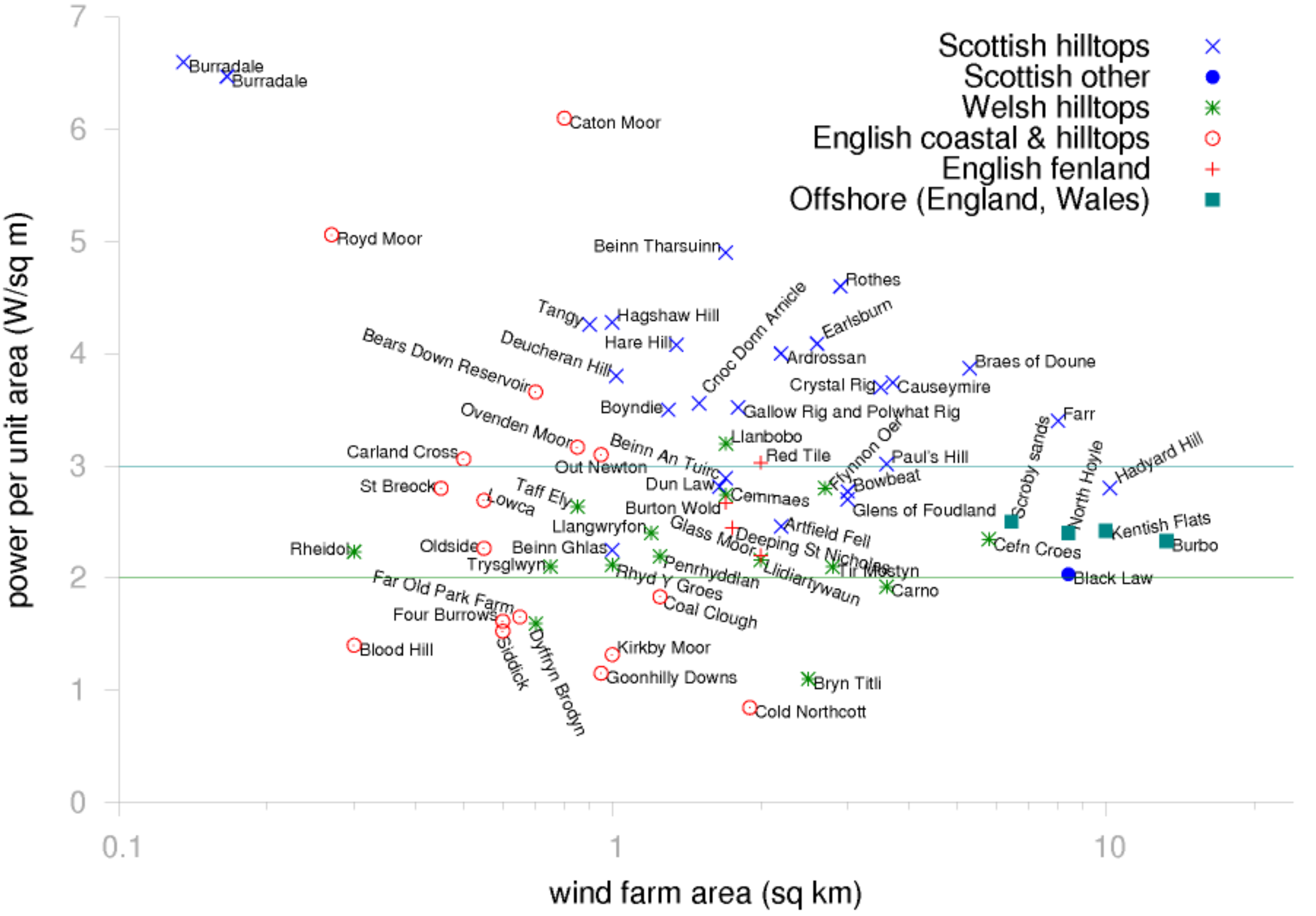
Turbine Summary

Wind turbine model	Bonus 2.3
No of turbines	40
Size of turbine (kW)	2,300
Rotor diameter (m)	
Hub height (m)	

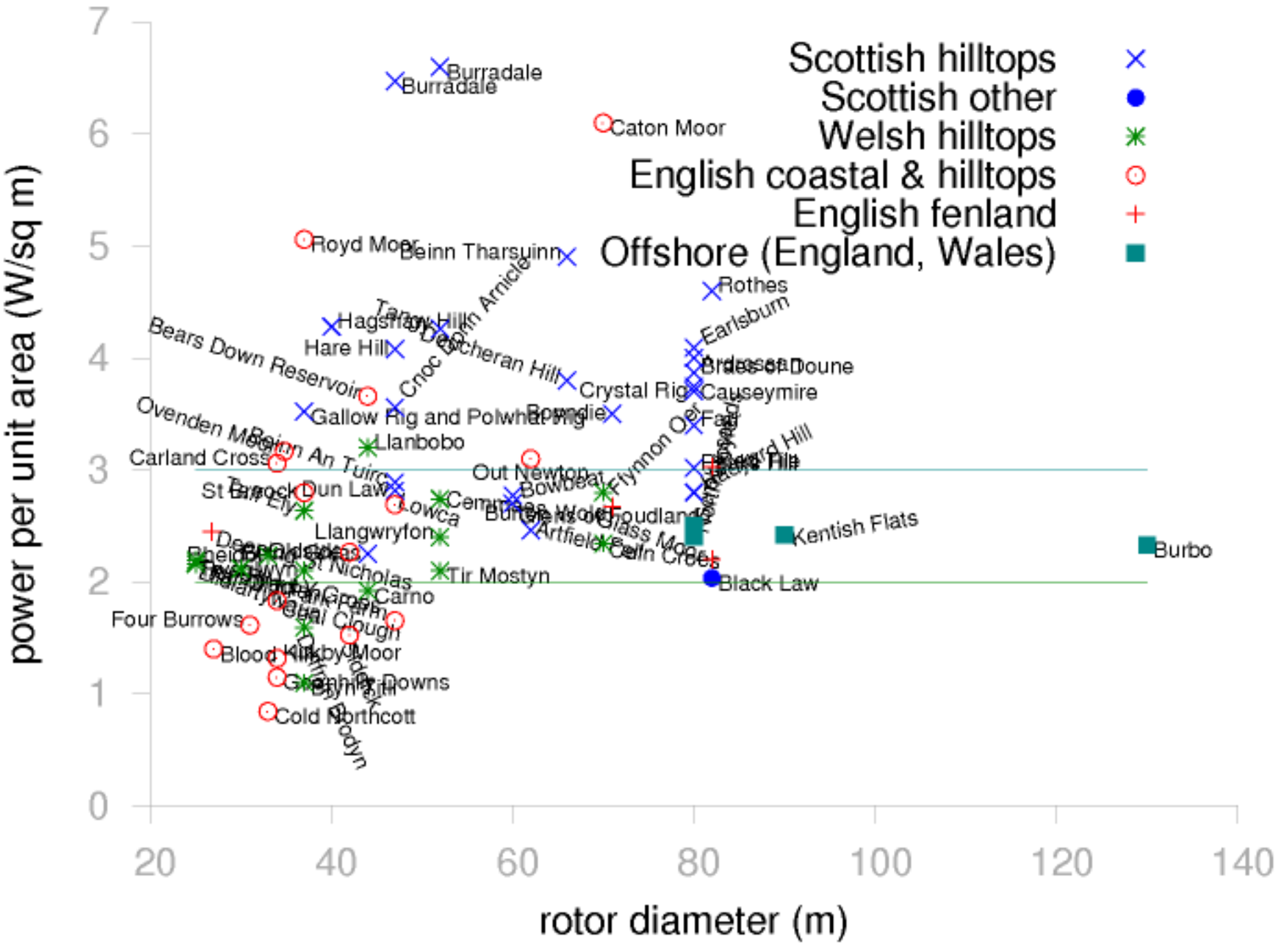


Distington
Trefenter
Tick Fen
Scroby Sands Wind Fm
Rhosybol
Oxenden
Wind Farm

Powers per unit area of British wind farms, v farm size



Powers per unit area of British wind farms, vs turbine diameter



Flight

$$7\,600\,\text{miles: one round-trip / year:}$$

$$\frac{2 \times 240\,000\,\text{litre}}{416\,\text{passengers}} \times 10\,\text{kWh/litre/year}$$

$$= 29\,\text{kWh/day}$$

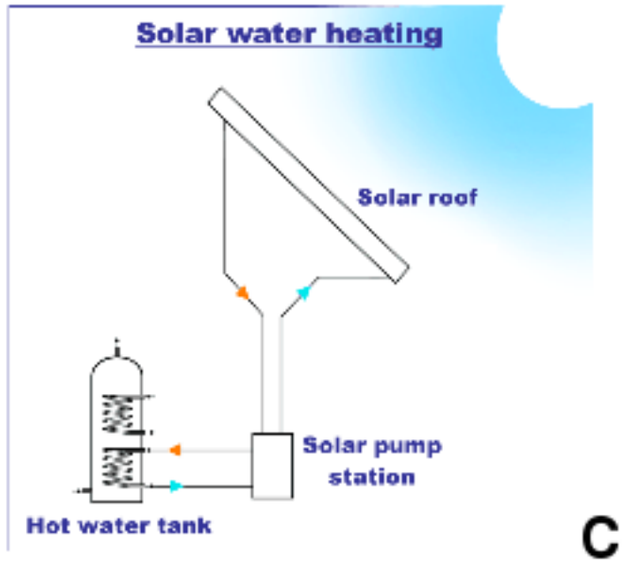
Jet flights:
30 kWh/d

Car:
40 kWh/d

Wind:
20 kWh/d

Solar

Solar thermal



Cover every south-facing roof

Jet flights:
30 kWh/d

Car:
40 kWh/d

$10\,\mathrm{m}^2$ per person:
13 kWh/day per person

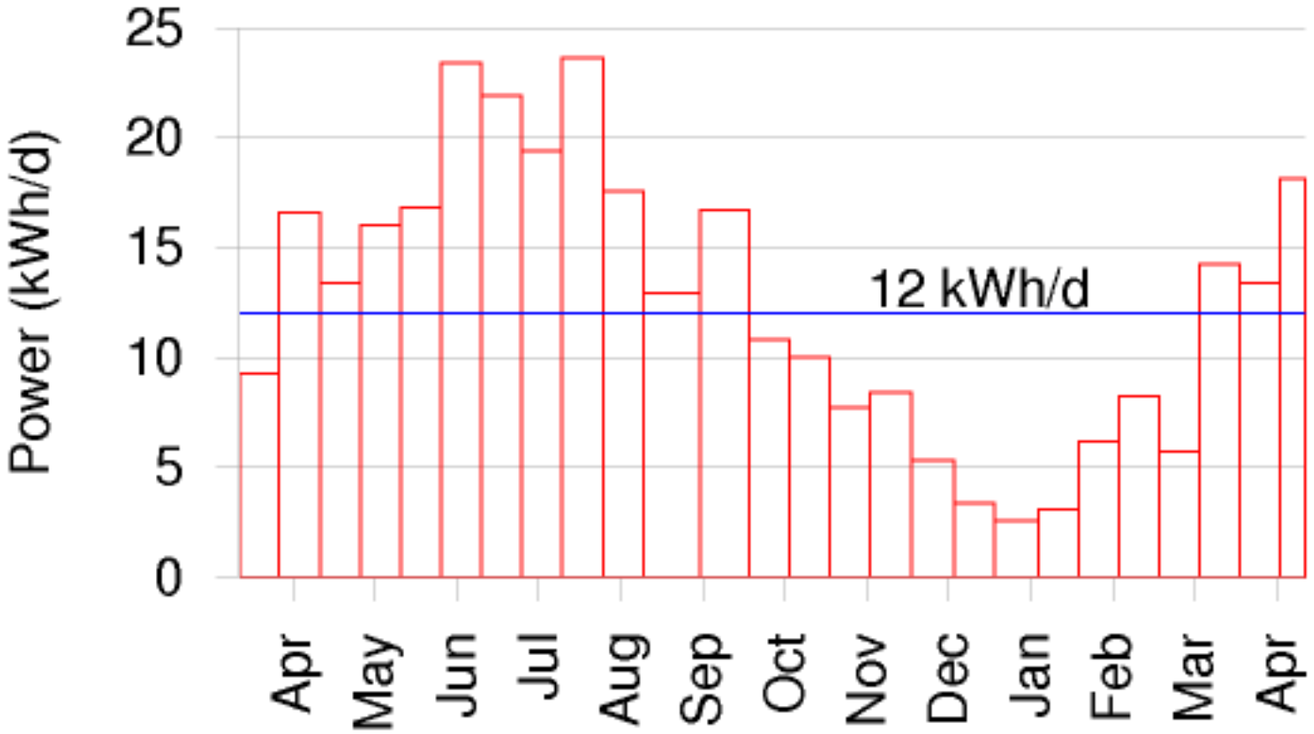
Solar heating:
13 kWh/d

Wind:
20 kWh/d

Solar electric (photovoltaics)

solarcentury

Solar electric



Data and photo by Jonathan Kimmitt

Cover *every South-facing roof*,
$10\,\mathrm{m}^2$ per person: $5\,\mathrm{kWh/day}$ per person

Jet flights:
30 kWh/d

Car:
40 kWh/d

PV, 10 m^2/p: **5**

Solar heating:
13 kWh/d

Wind:
20 kWh/d

Solar PV farming

Bavaria Solar Park: $5\,\mathrm{W/m^2}$; this picture shows $0.7\,\mathrm{MW}$ (average)

Solar PV (covering 5% of the country)

Jet flights:
30 kWh/d

Car:
40 kWh/d

PV farm
(200 m^2/p):
50 kWh/d

PV, 10 m^2/p: **5**

Solar heating:
13 kWh/d

Wind:
20 kWh/d

Solar biomass

- Best plants (0.5% efficient)
  - cover 75% of the country;
  - 1/3 lost in processing.

Jet flights: **30 kWh/d**

Car: **40 kWh/d**

Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**

PV farm (200 m^2/p): **50 kWh/d**

PV, 10 m^2/p: **5**

Solar heating: **13 kWh/d**

Wind: **20 kWh/d**

includes

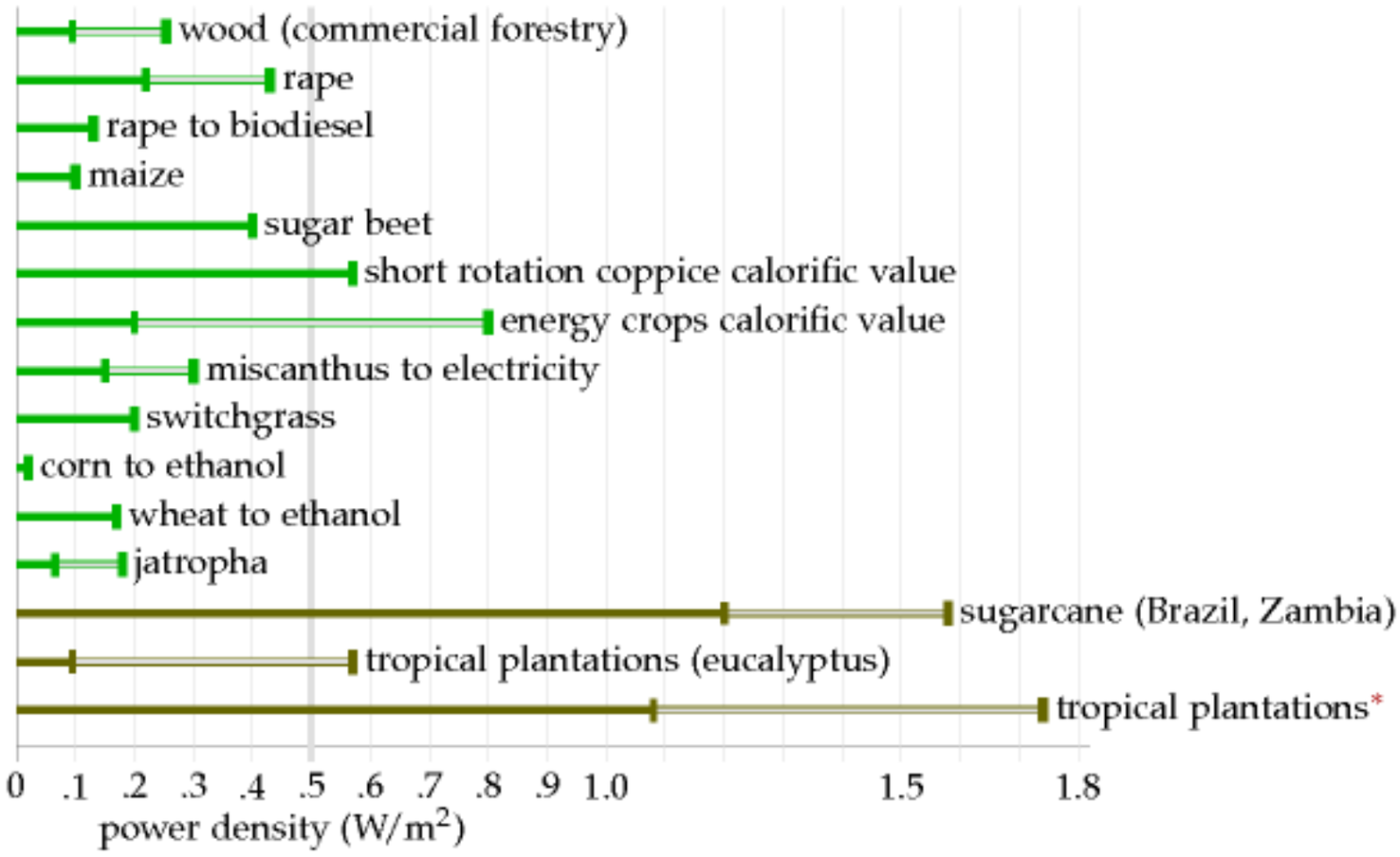
sustainable waste incineration

cellulosic ethanol

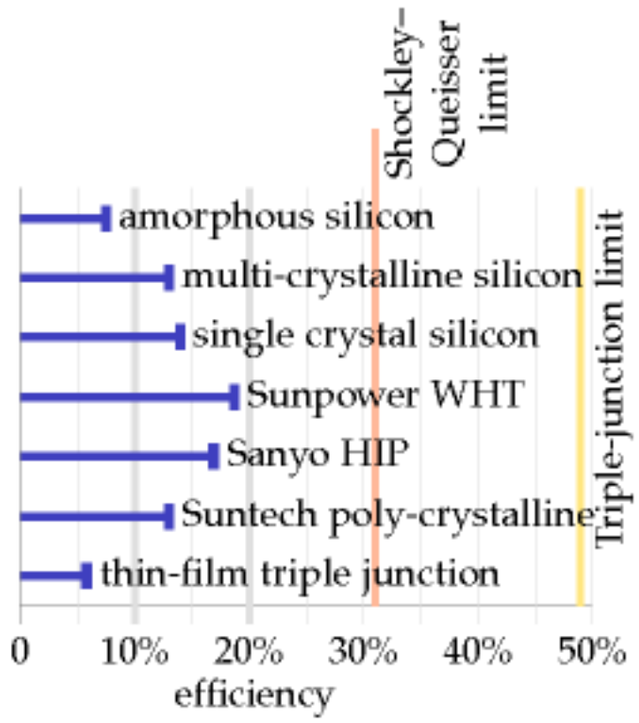
methanol

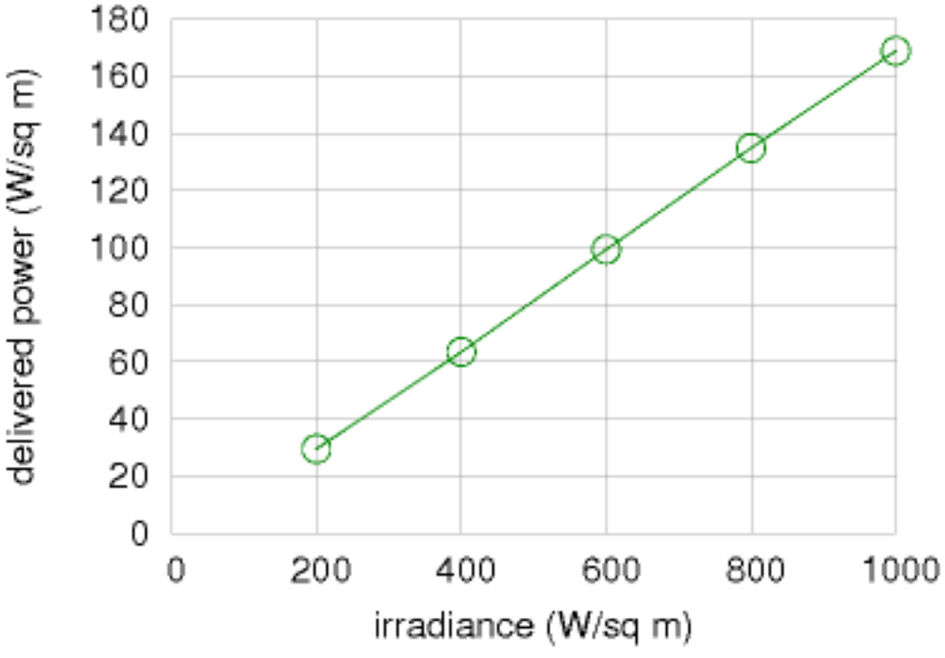
Average solar intensity, UK: 100 W per square metre

Plant power per unit area



PV efficiencies





Heating and cooling

Hot water

Bath: 5 kWh

Shower: 1.4 kWh

Clothes wash: 1 kWh

Cooking, kettle, microwave, dishes

Hot water:
12 kWh/d

Hot air

Hot air:
24

Fridge, Airconditioning

Cooling: **1 kWh/d**

Heating, cooling:
37 kWh/d

Jet flights:
30 kWh/d

Car:
40 kWh/d

Biomass: food, biofuel, wood, waste incin'n, landfill gas:
24 kWh/d

PV farm (200 m^2/p):
50 kWh/d

PV, 10 m^2/p: **5**

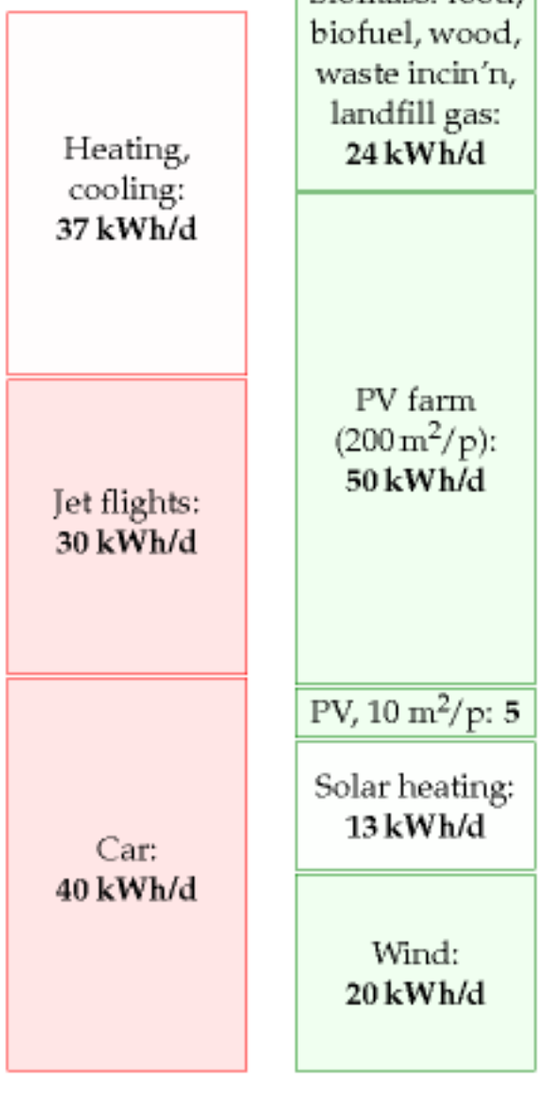
Solar heating:
13 kWh/d

Wind:
20 kWh/d

Hydro

- 1.5 kWh/d per person

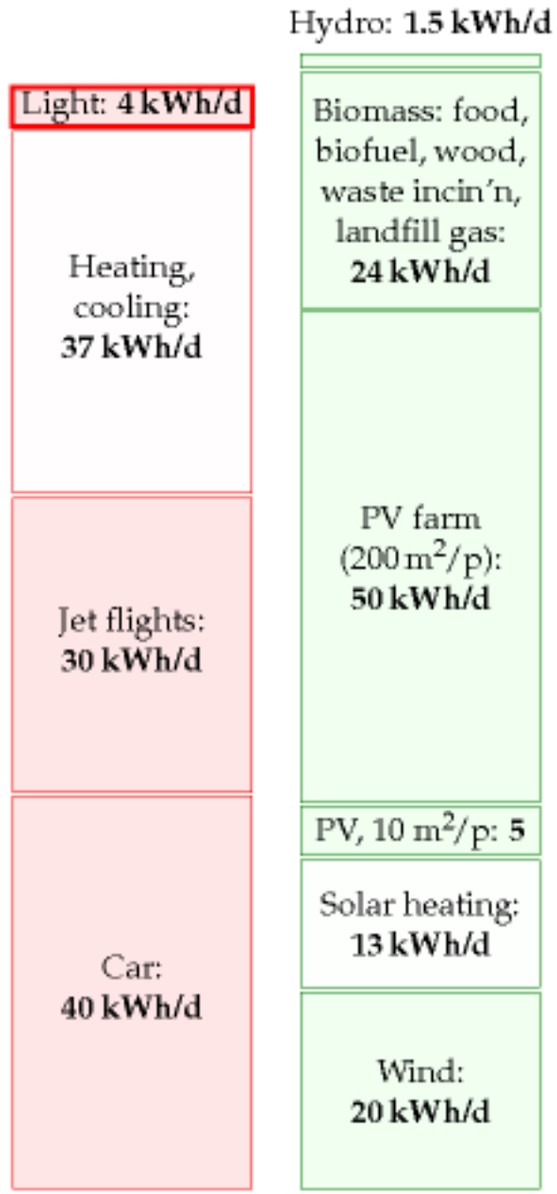
(currently 0.2 kWh/d per person)



Nant-y-Moch by Dave Newbould
www.origins-photography.co.uk

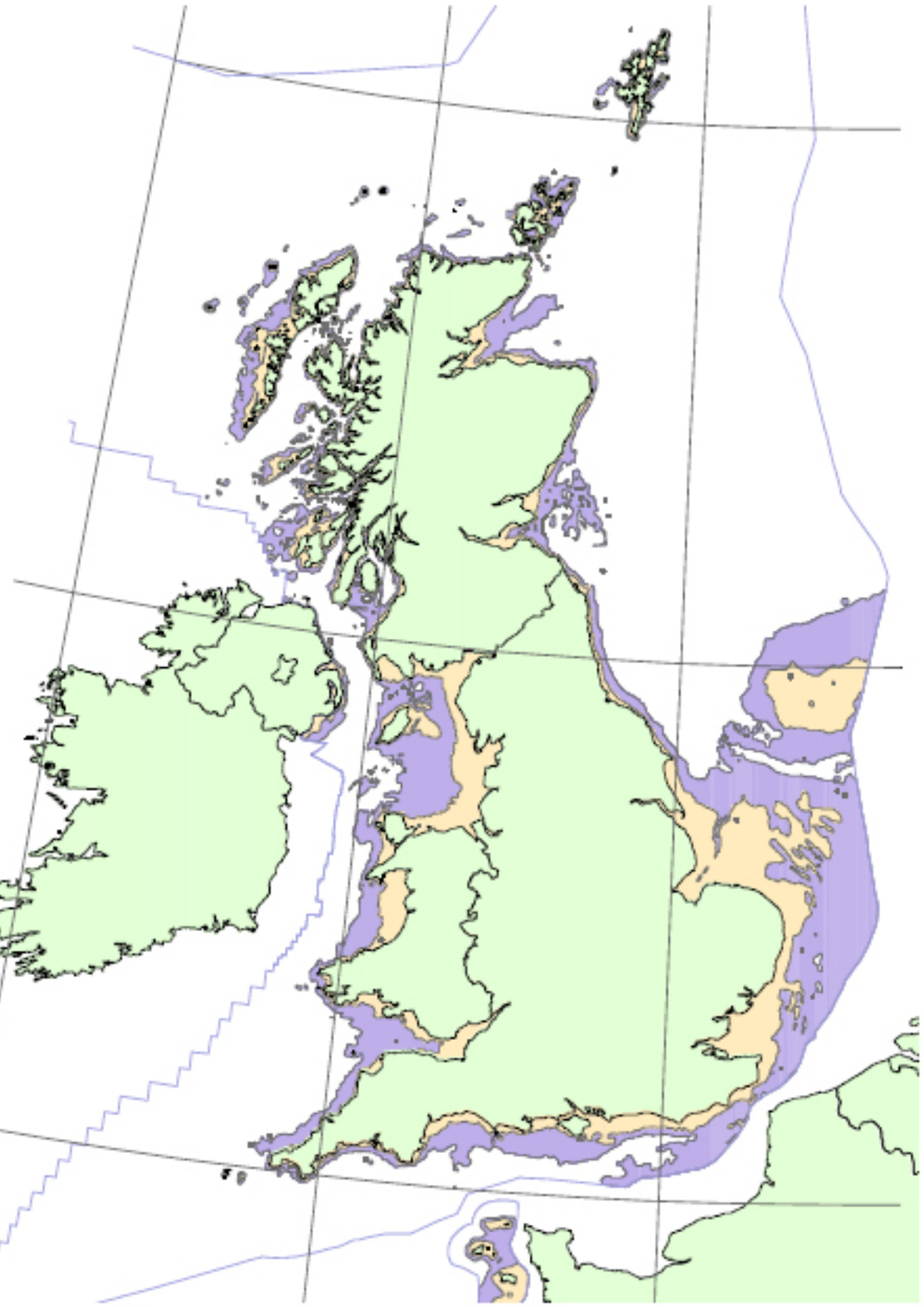
Light

- 10 bulbs
- 5 hours per day



Offshore wind

$3\ \mathrm{W/m^2}$



depth less than 25m (yellow); depth between 25m and 50m (magenta).
Data from DTI Atlas of Renewable Marine Resources. Crown copyright.

Shallow offshore wind: **16 kWh/d**

Hydro: **1.5 kWh/d**

Light: **4 kWh/d**

Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**

Heating, cooling: **37 kWh/d**

PV farm (200 m^2/p): **50 kWh/d**

Jet flights: **30 kWh/d**

PV, 10 m^2/p: **5**

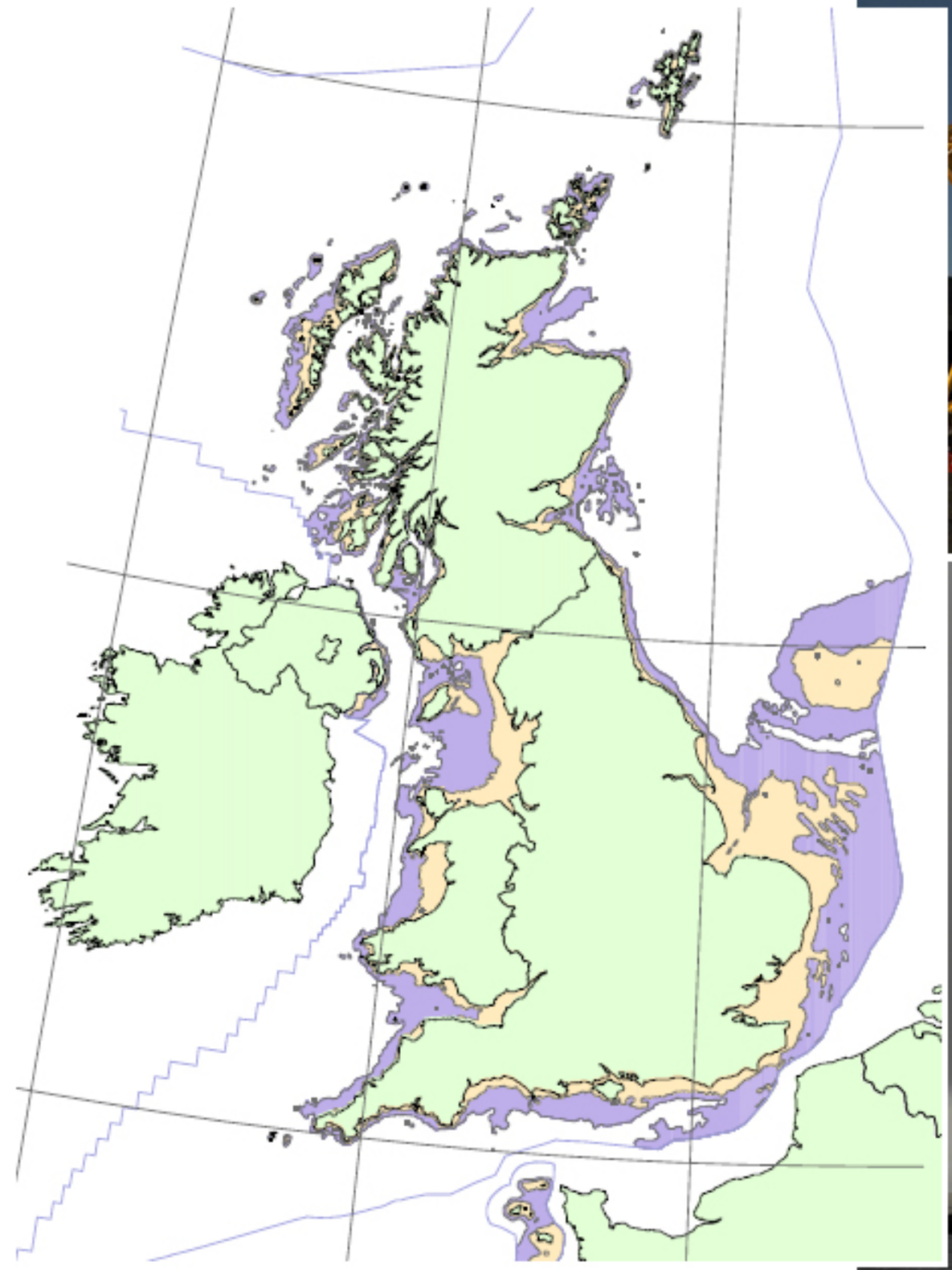
Solar heating: **13 kWh/d**

Car: **40 kWh/d**

Wind: **20 kWh/d**

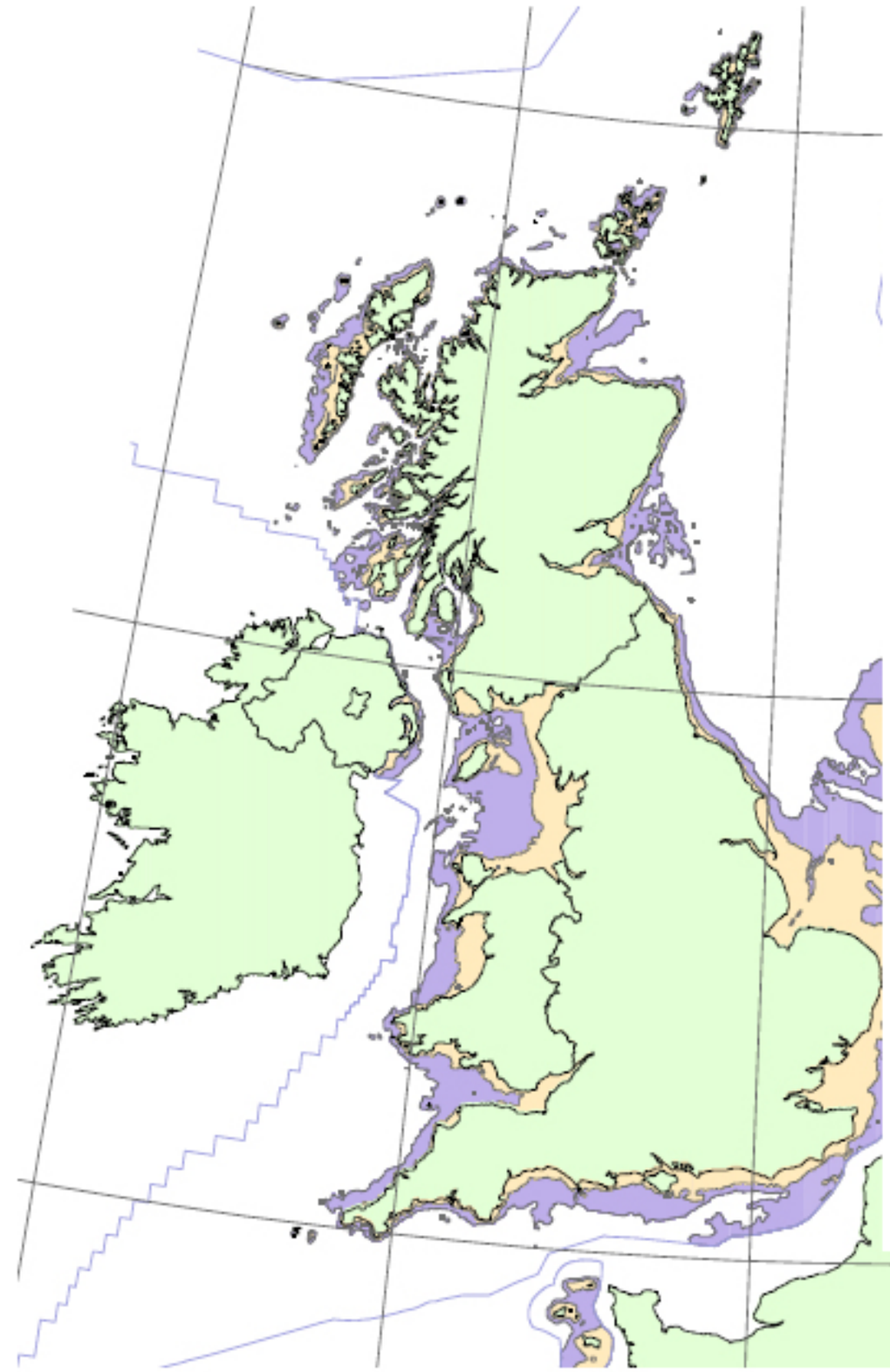
(c) Elsam (elsam.com).
Used with permission.

Deep offshore wind



depth less than 25m (yellow); depth between 25m and 50m (magenta).

Deep offshore wind



depth less than 25m (yellow); depth between 25m and 50m (magenta).

Light: **4 kWh/d**

Heating, cooling: **37 kWh/d**

Jet flights: **30 kWh/d**

Car: **40 kWh/d**

Deep offshore wind: **32 kWh/d**

Shallow offshore wind: **16 kWh/d**

Hydro: **1.5 kWh/d**

Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**

PV farm (200 m^2/p): **50 kWh/d**

PV, 10 m^2/p: **5**

Solar heating: **13 kWh/d**

Wind: **20 kWh/d**

48 kWh/d per person -

60 Mt of concrete and steel (1 t per person)

Area required: two Waleses

Gadgets

- TV
- Computer
- Cable modem
- Mobile phones
- Bedside radio
- Other gadgets

Charger left plugged in:

0.01 kWh/d

Gadgets: **5**

Light: **4 kWh/d**

Heating, cooling: **37 kWh/d**

Jet flights: **30 kWh/d**

Car: **40 kWh/d**

Deep offshore wind: **32 kWh/d**

Shallow offshore wind: **16 kWh/d**

Hydro: **1.5 kWh/d**

Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**

PV farm (200 m^2/p): **50 kWh/d**

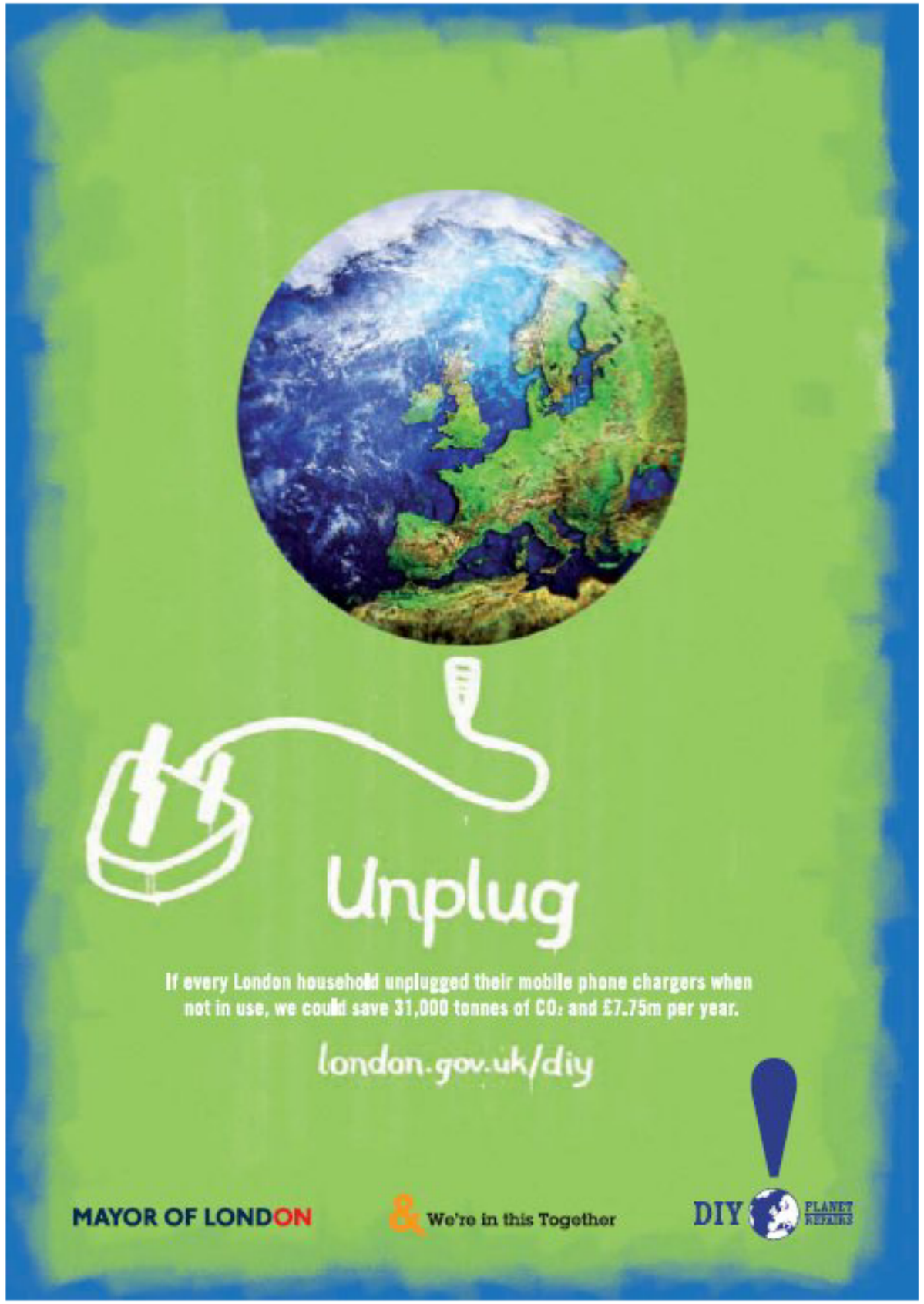
PV, 10 m^2/p: **5**

Solar heating: **13 kWh/d**

Wind: **20 kWh/d**

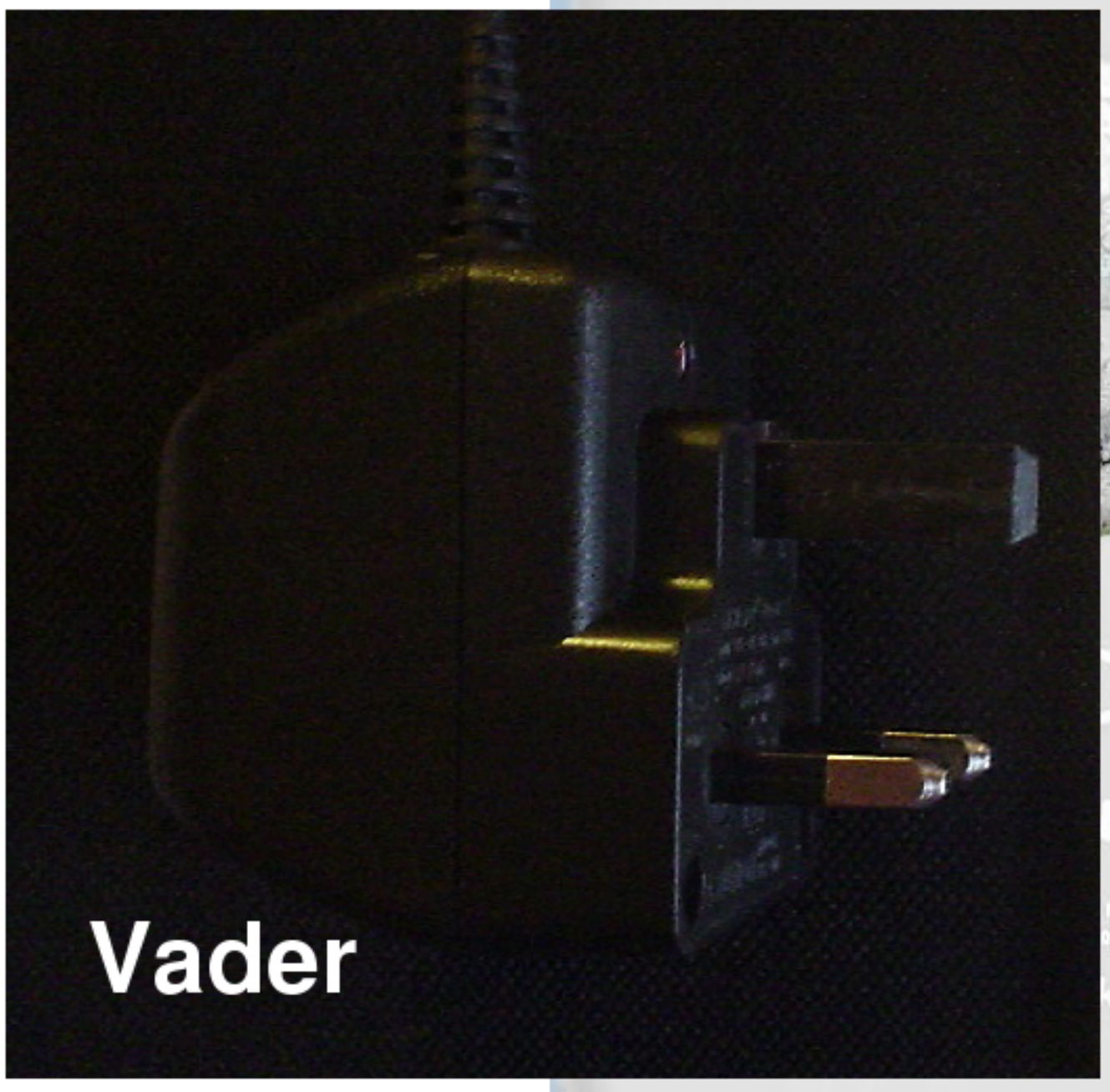
f, 4f

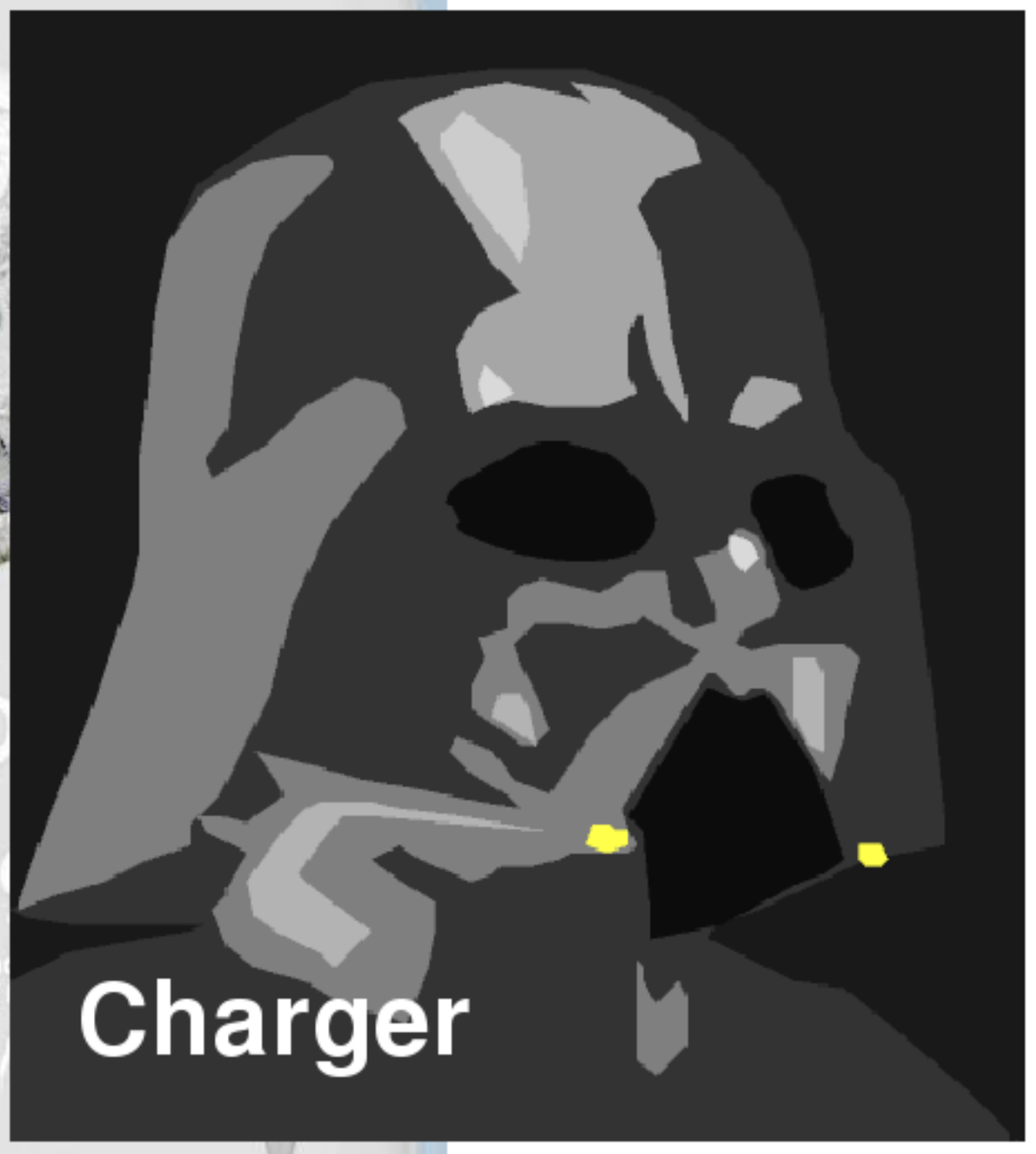
June 2007



'If every London household unplugged their mobile phone chargers when not in use, we could save 31,000 tonnes of CO2 and 7.75m per year.'

Are they related?

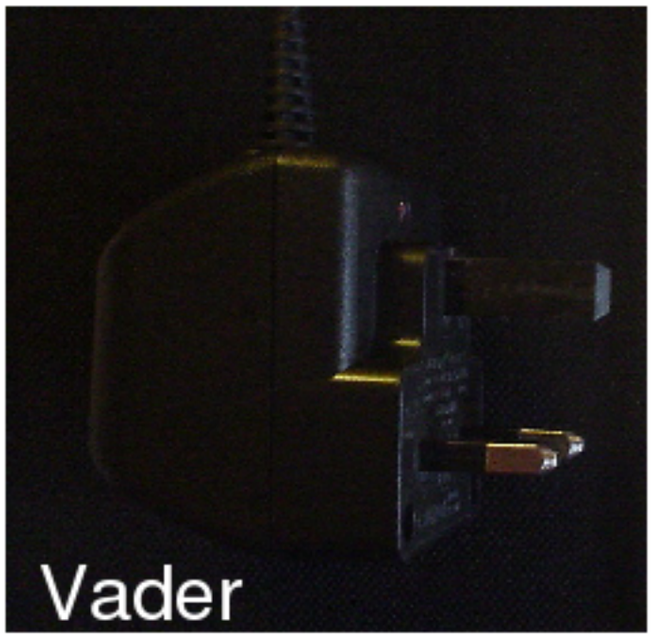




MAYOR OF LONDON We're in this Together DIY PLANET REPAIRS

'If every London household unplugged their mobile phone chargers when not in use, we could save 31,000 tonnes of CO2 and 7.75m per year.'

Numbers

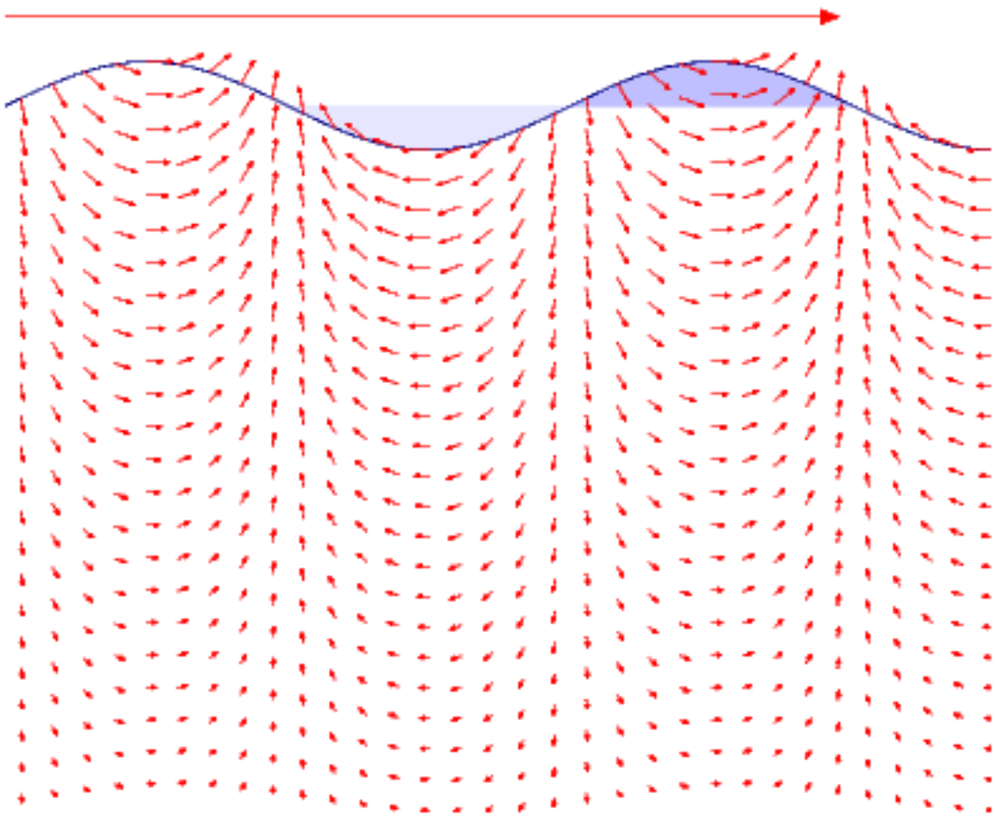


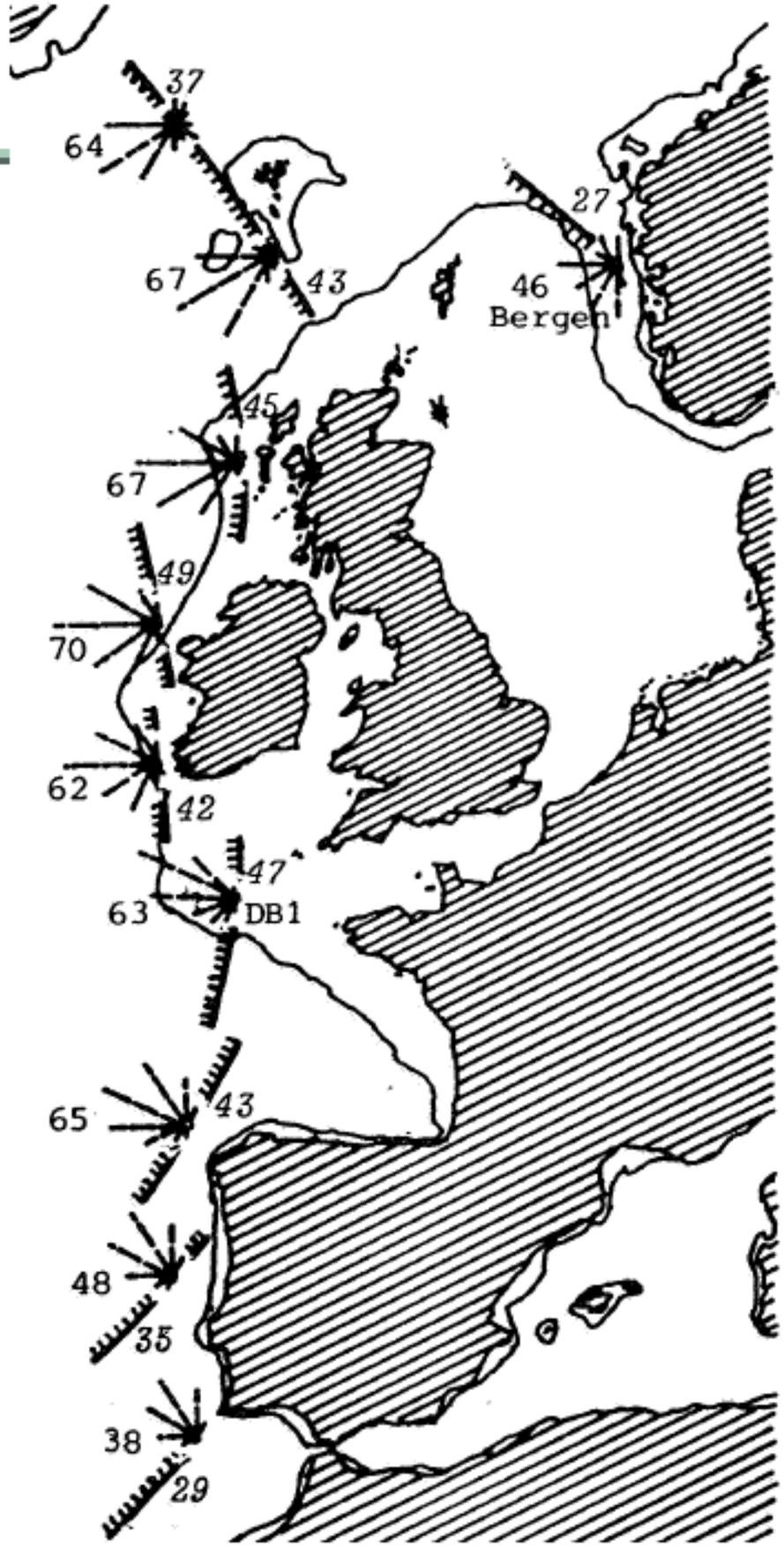
Energy saved by switching off for one day = Energy used by driving an average car for one second

$$0.5\,\mathrm{W} \times 86\,400\,\mathrm{s} = 40\,000\,\mathrm{W} \times 1\,\mathrm{s}$$

$$0.01\,\mathrm{kWh}$$

Wave





D. Mollison: Wave climate and the wave power resource (1986)

Wave

Gadgets: **5**

Light: **4 kWh/d**

Heating, cooling: **37 kWh/d**

Jet flights: **30 kWh/d**

Car: **40 kWh/d**

Wave: **4 kWh/d**

Deep offshore wind: **32 kWh/d**

Shallow offshore wind: **16 kWh/d**

Hydro: **1.5 kWh/d**

Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**

PV farm (200 m^2/p): **50 kWh/d**

PV, 10 m^2/p: **5**

Solar heating: **13 kWh/d**

Wind: **20 kWh/d**

'500 kW' Limpet, Islay

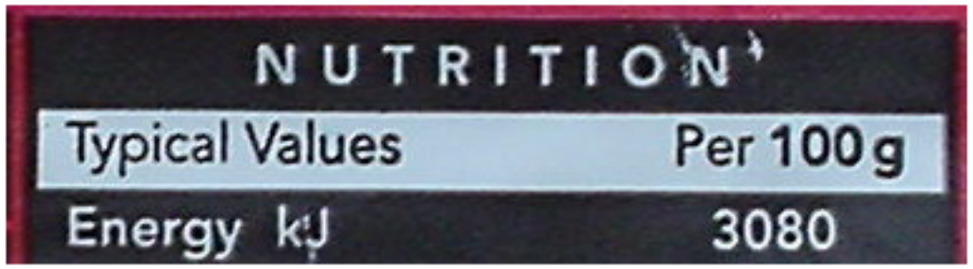
Predicted average power: 200kW. Actual: 21kW.

Total incident power / population of UK

$$= \frac{40\,\text{kW/metre} \times 1000\,\text{km}}{60 \times 10^6} = 16\,\text{kWh/day}$$

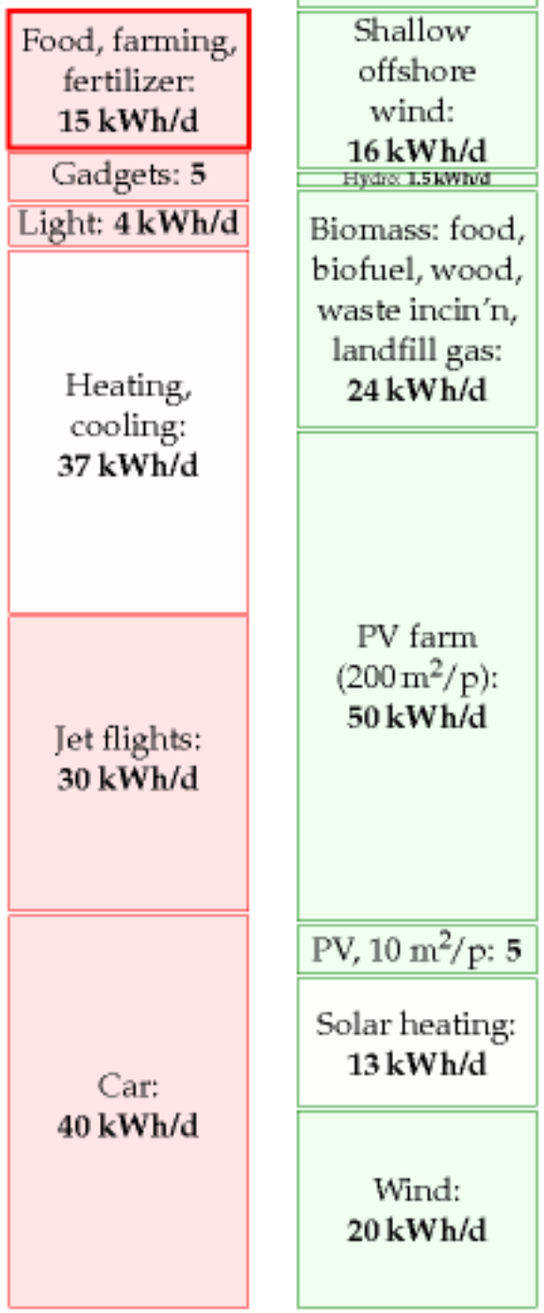
Ocean Power Delivery (ocea

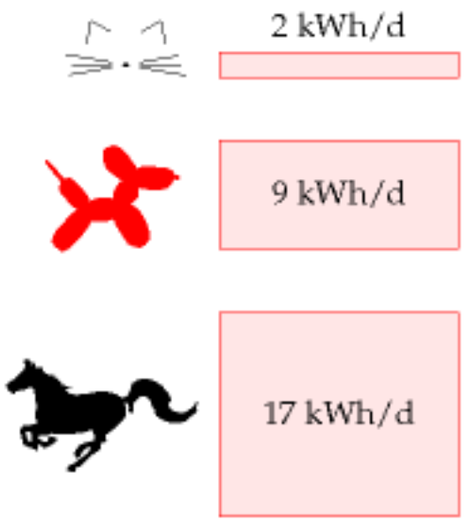
Food'n'Farming



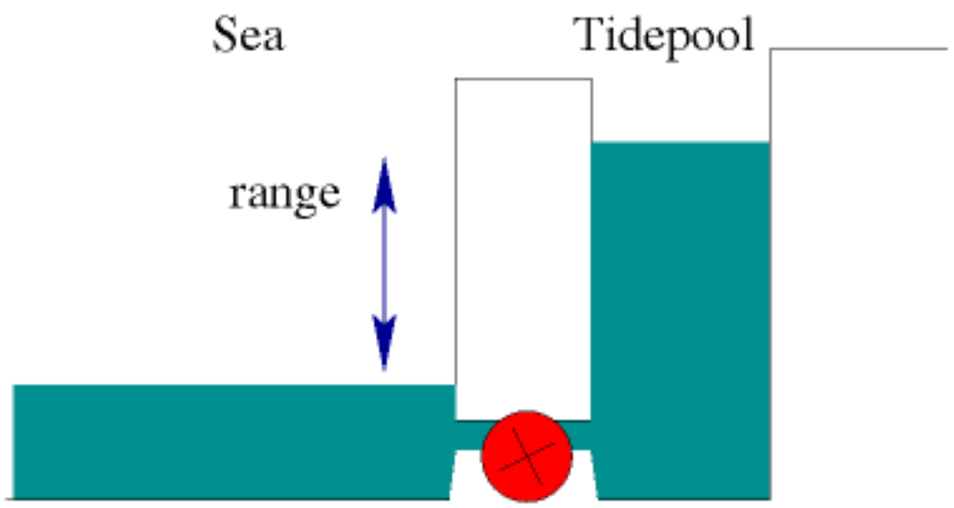
(not including energy for food delivery)

Vegans: 3 kWh/d minimum
Vegetarians: 4 kWh/d min
Carnivores: 12 kWh/d min
(260 kg of animal preparing to be eaten)



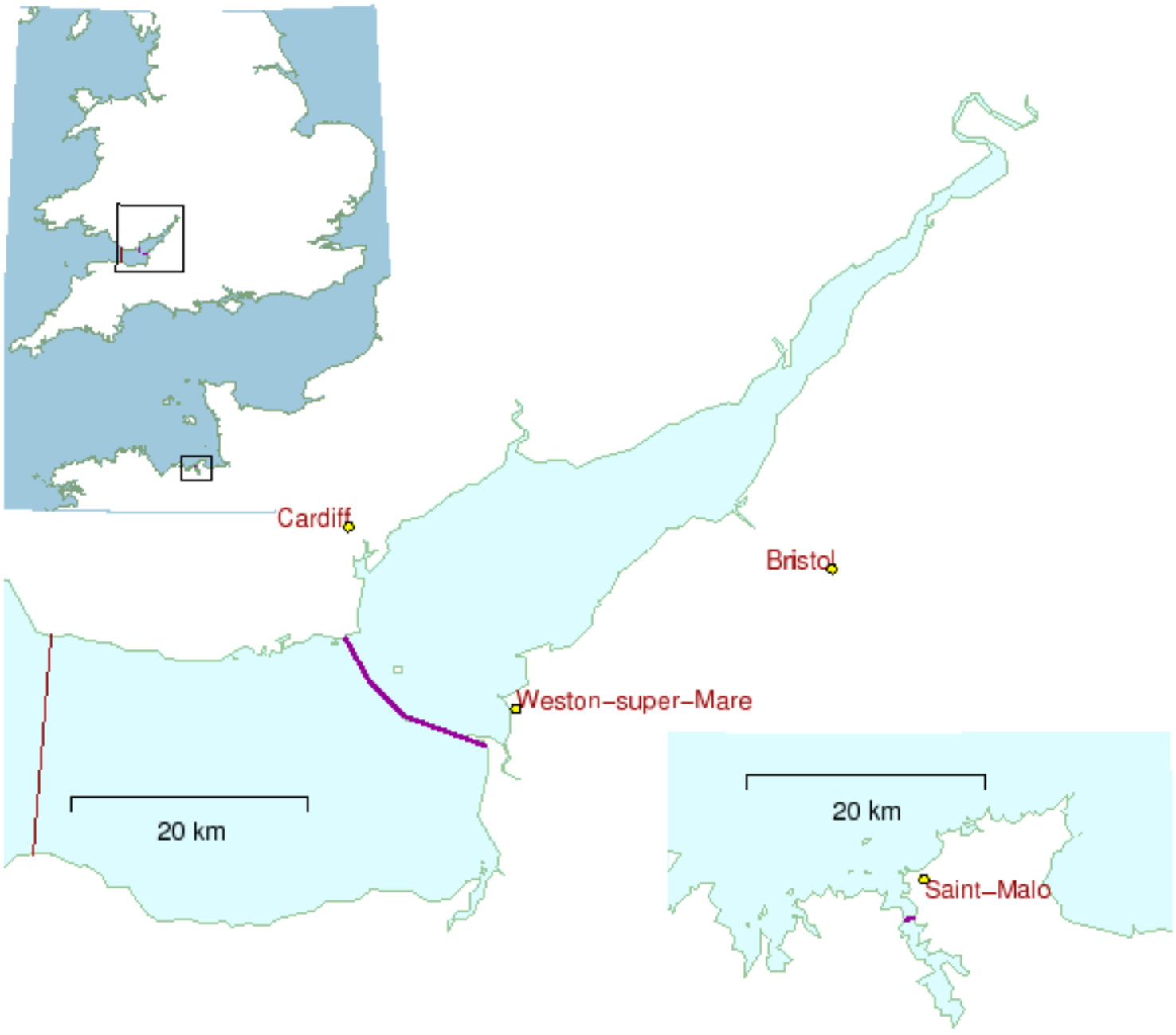


Tide - using tide pools



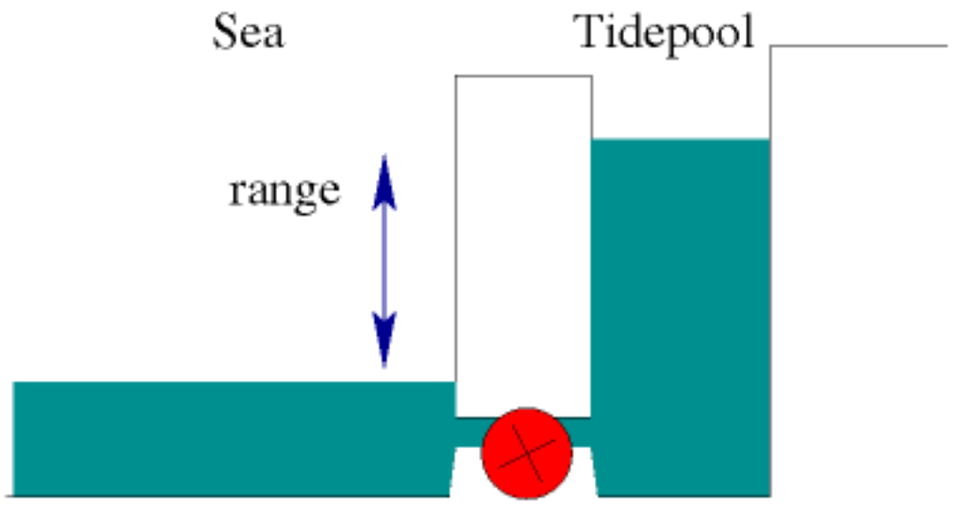
Tide Mill, Woodbridge, since 1170

Severn barrage and la Rance

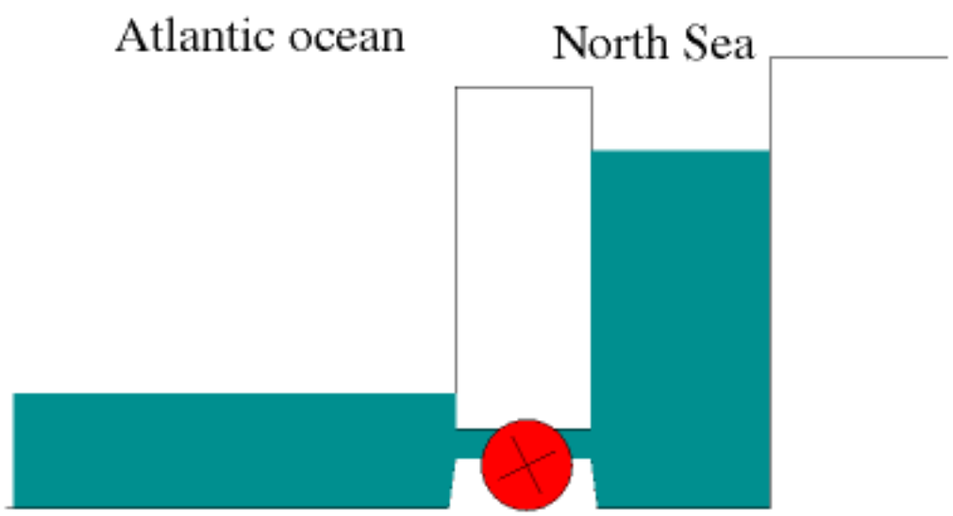


La Rance (60 MW): **2.7** W/m^2

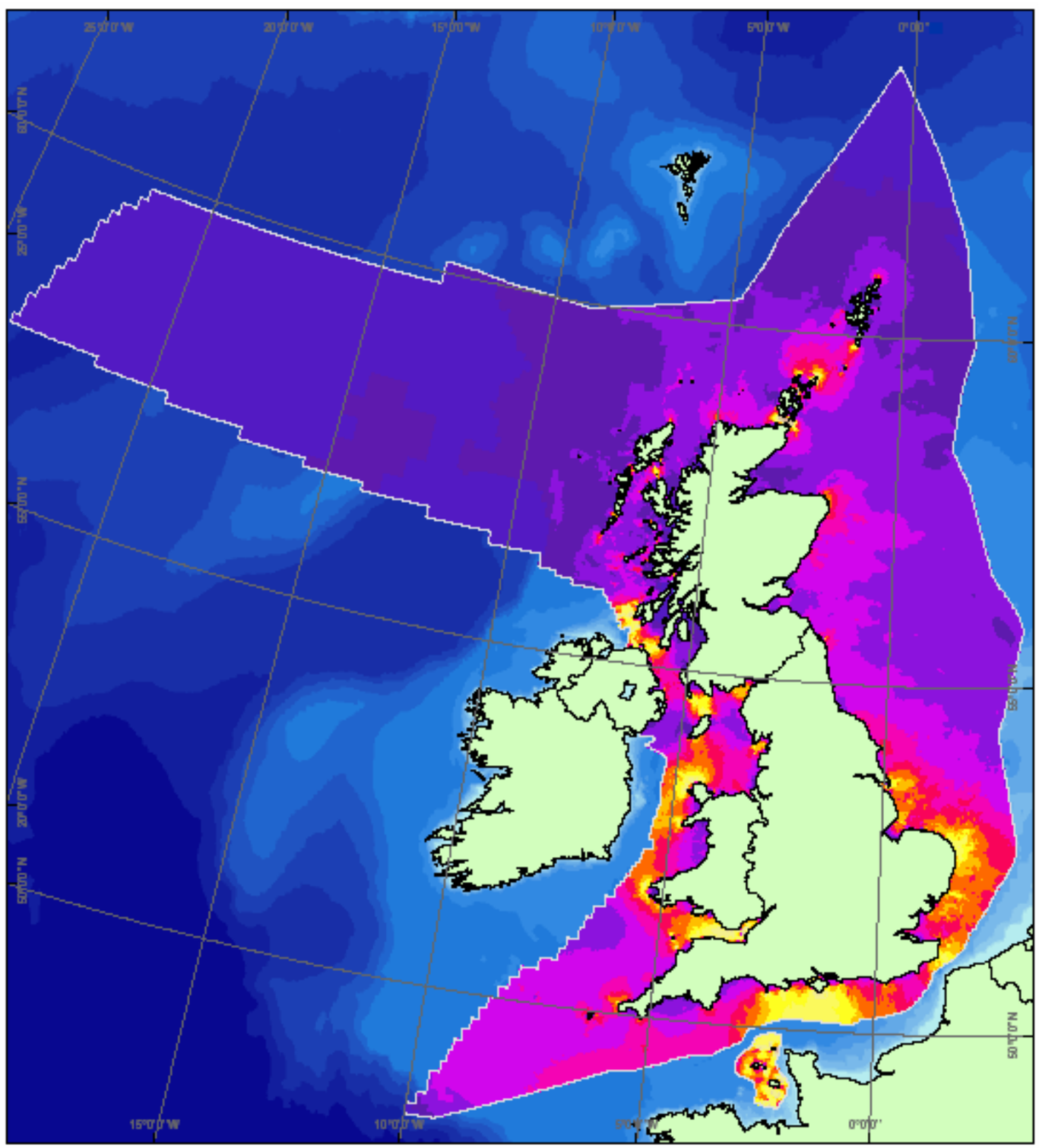
Tide - using tide pools

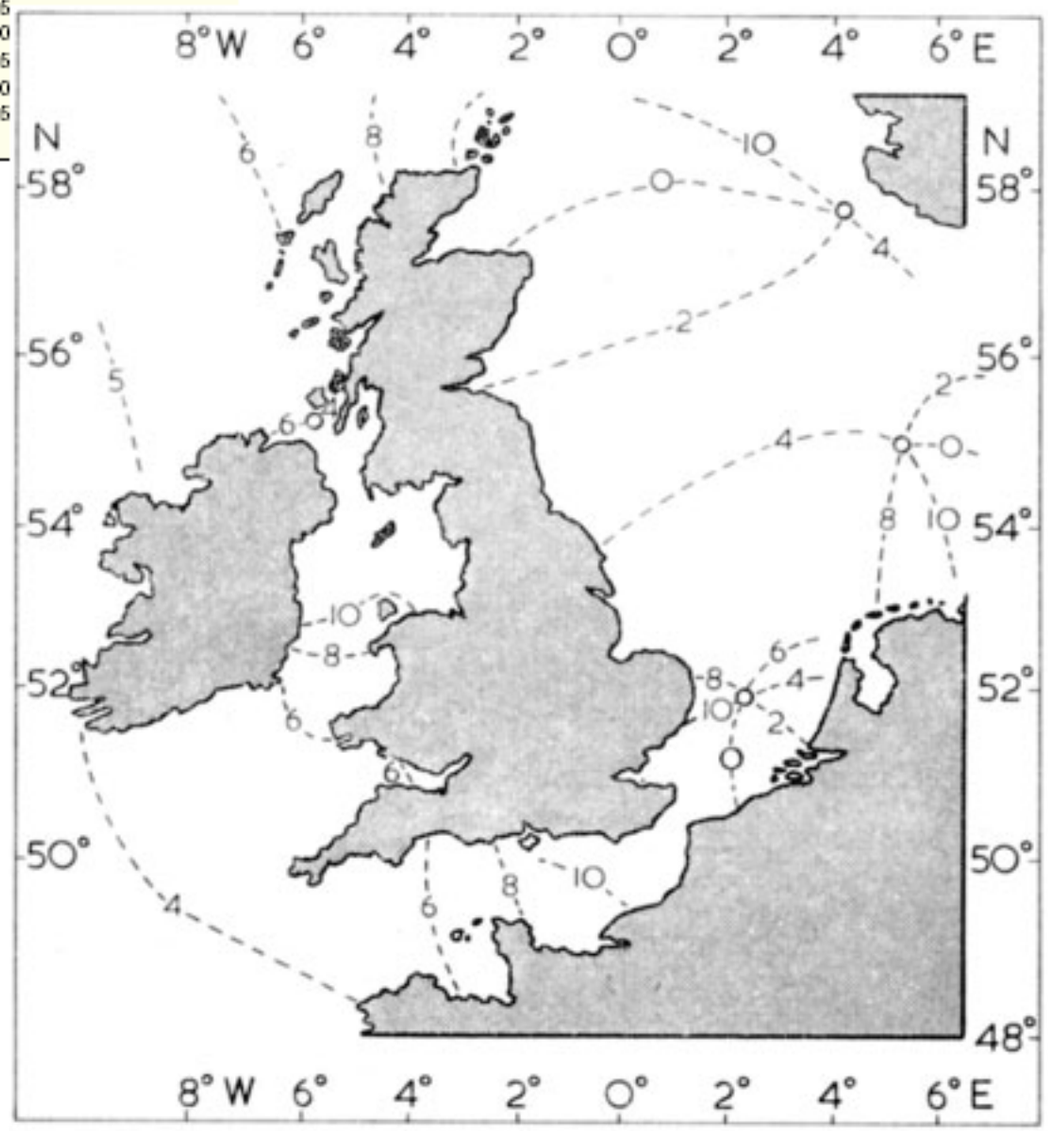


Tidal range	Power per unit area
4 m	3 W/m^2



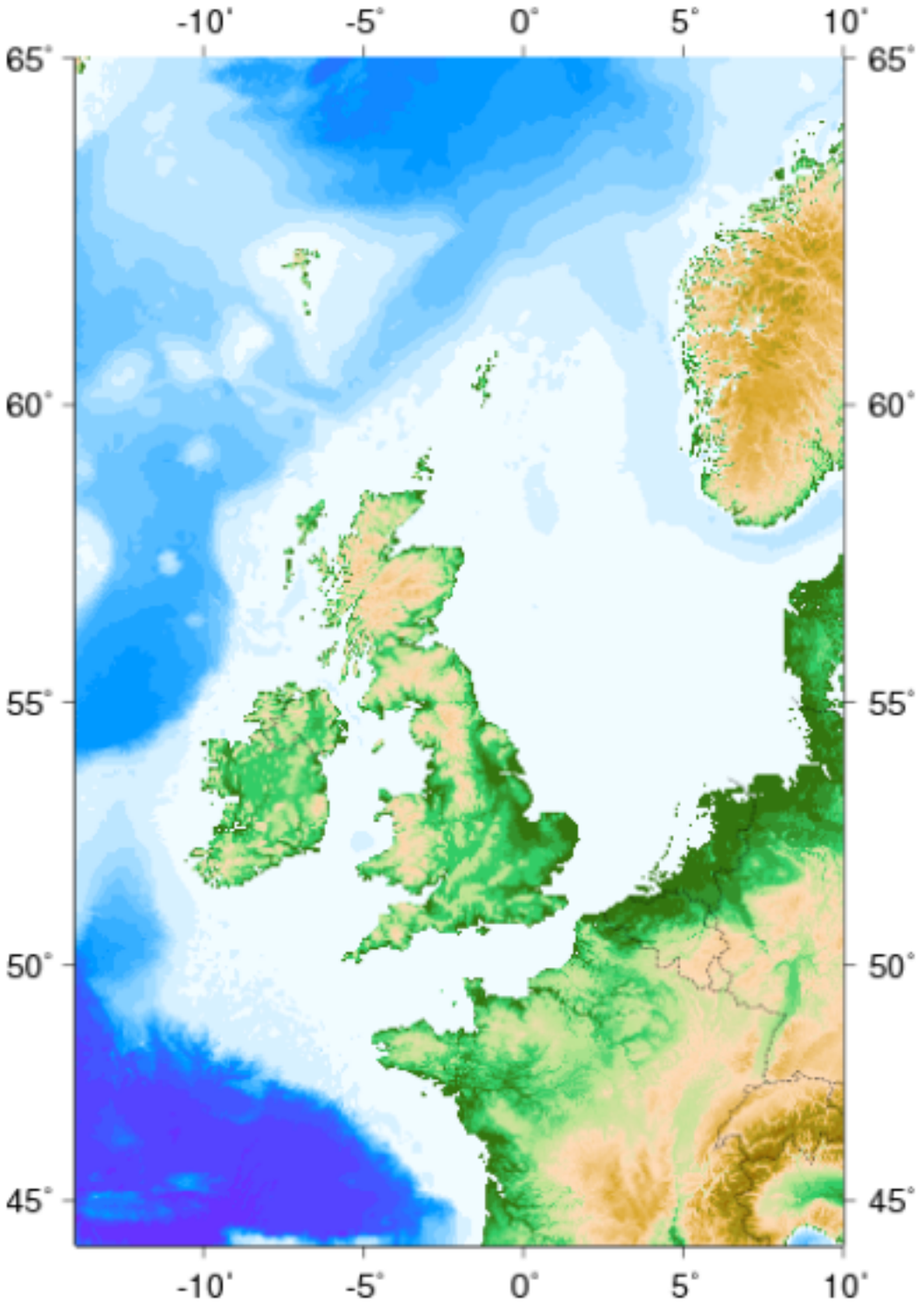
Tide


Peak Flow - (m/s)
> 4.01
3.51 - 4.00
3.01 - 3.50
2.51 - 3.00
2.01 - 2.50
1.76 - 2.00
1.51 - 1.75
1.26 - 1.50
1.01 - 1.25
0.76 - 1.00
0.51 - 0.75
0.26 - 0.50
0.11 - 0.25
< 0.10
Land
UK Continental Shelf & Channel Island Territorial Sea Limit


8° W
6°
4°
2°
0°
2°
4°
6° E
N
58°
56°
54°
52°
50°
48°

DTI

Total incoming power in 'tidal waves'



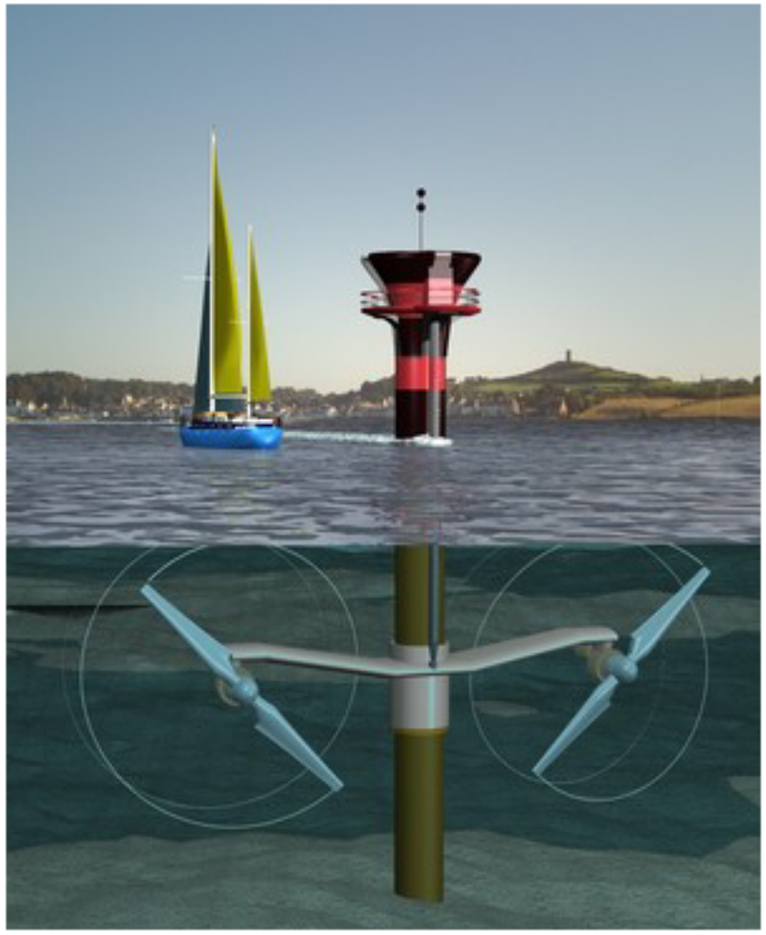
~300 kW per metre

Total: 250 GW

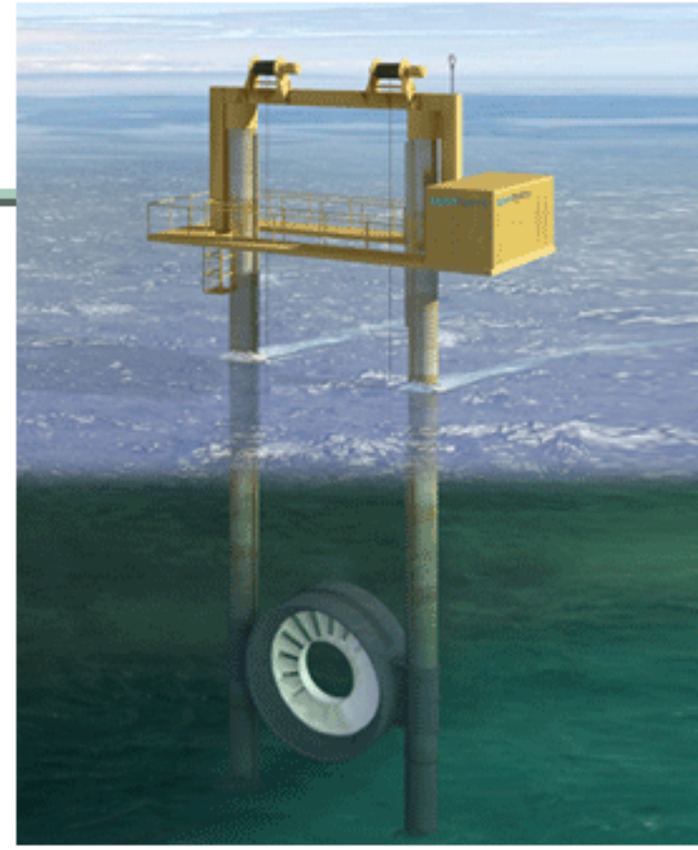
(100 kWh/d per person)

Cartwright et al (1980) Phil Trans R S Series A

Tidal stream power



marineturbines.com

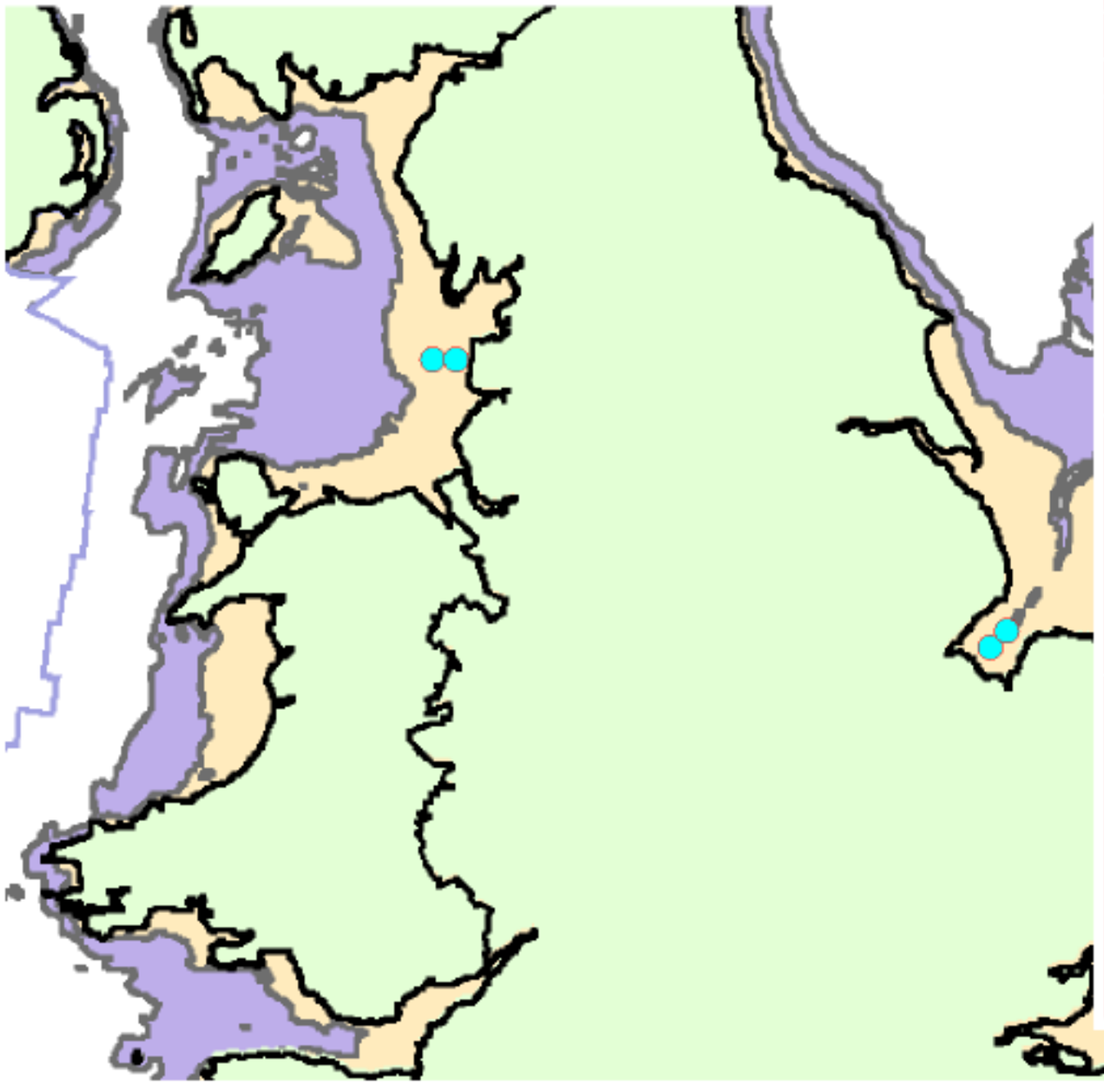


Open Hydro

1kWh/d/person
(DTI figure)

Tide

- Tide farms
- Tidal lagoons



Food, farming, fertilizer: **15 kWh/d**

Gadgets: **5**

Light: **4 kWh/d**

Heating, cooling: **37 kWh/d**

Jet flights: **30 kWh/d**

Car: **40 kWh/d**

Tide: **11 kWh/d**

Wave: **4 kWh/d**

Deep offshore wind: **32 kWh/d**

Shallow offshore wind: **16 kWh/d**

Hydro: 1.5 kWh/d

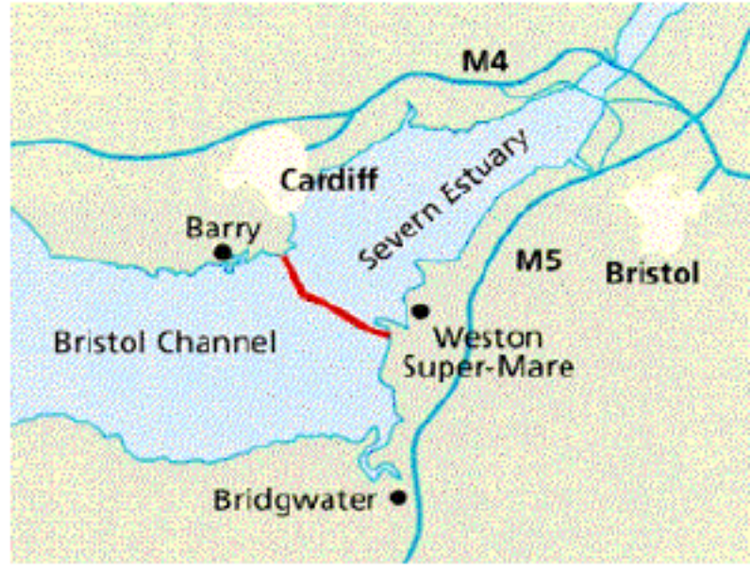
Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**

PV farm (200 m^2/p): **50 kWh/d**

PV, 10 m^2/p: **5**

Solar heating: **13 kWh/d**

Wind: **20 kWh/d**



and barrages

0.8 kWh/d per person

Stuff

- One new computer every 2 years

Chips: **2.5 kWh/d**

Aluminium: **3 kWh/d**

- 5 cans per day
- Stuff made in China: 12 kWh/d/p
- Transporting rubbish around

Road freight: **7 kWh/d**

Supermarkets: **0.5 kWh/d**

Shipping: **4**

Newspapers, junk mail, magazines: **2 kWh/d**

Transporting stuff: **12 kWh/d**

Stuff: **48+ kWh/d**

Food, farming, fertilizer: **15 kWh/d**

Gadgets: **5**

Light: **4 kWh/d**

Heating, cooling: **37 kWh/d**

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Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**

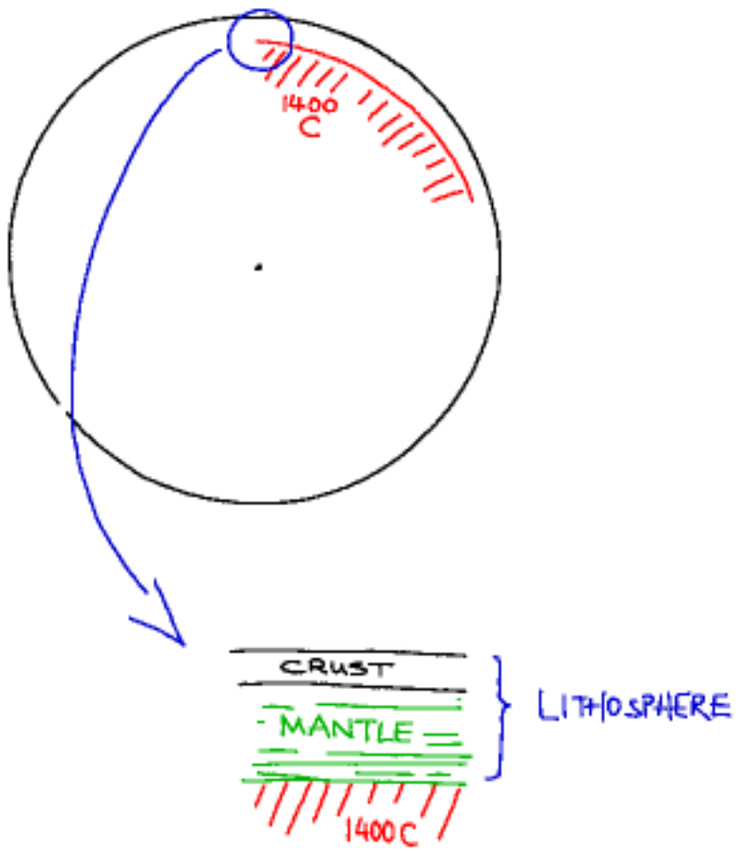
Photos by Chris Jordan

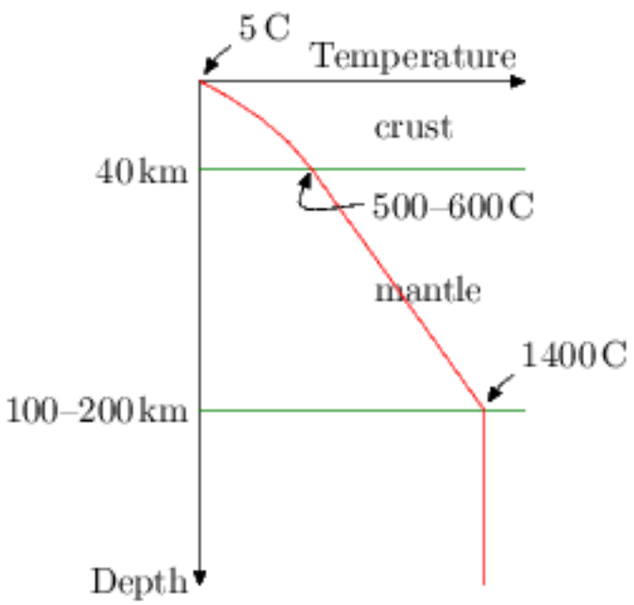
Geothermal

Nesjavellir, Iceland

Average geothermal electricity generation in Iceland in 2006 was 300 MW (24 kWh/d/person)

Geothermal





Transporting stuff: **12 kWh/d**

Stuff: **48+ kWh/d**

Food, farming, fertilizer: **15 kWh/d**

Gadgets: **5**

Light: **4 kWh/d**

Heating, cooling: **37 kWh/d**

Jet flights: **30 kWh/d**

Car: **40 kWh/d**

Geothermal: **1 kWh/d**

Tide: **11 kWh/d**

Wave: **4 kWh/d**

Deep offshore wind: **32 kWh/d**

Shallow offshore wind: **16 kWh/d**

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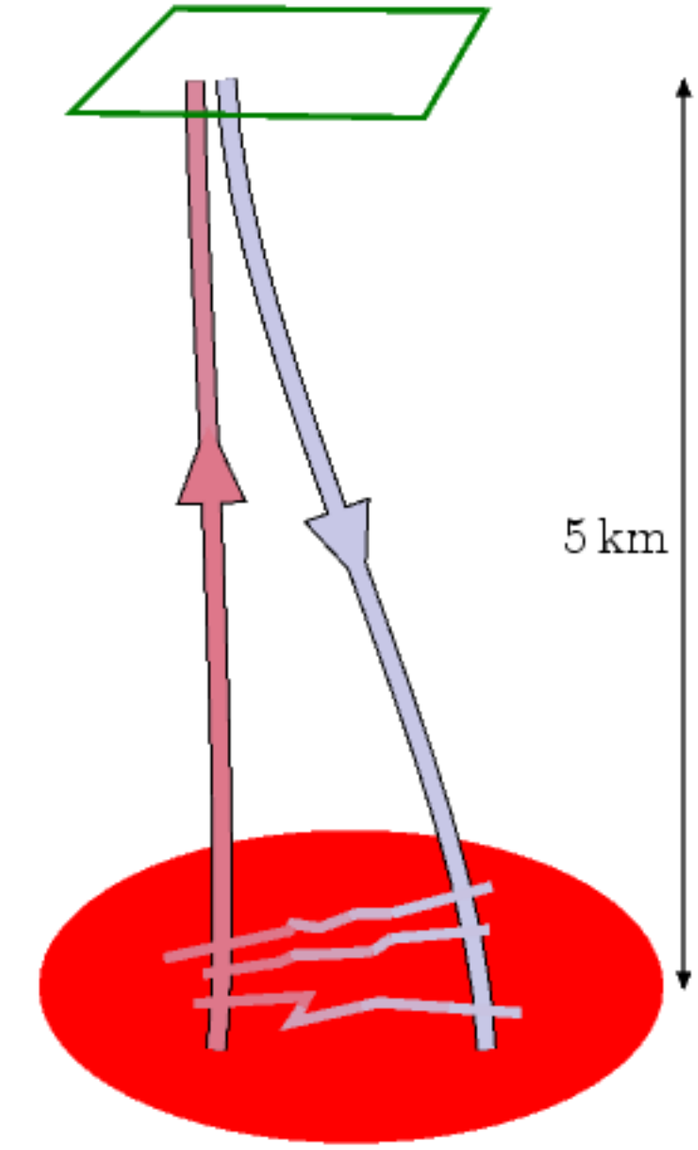
Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**

PV farm (200 m^2/p): **50 kWh/d**

PV, 10 m^2/p: **5**

Solar heating: **13 kWh/d**

Wind: **20 kWh/d**



'Hot dry rock'

The Salt Lake Tribune

SATURDAY, September 19, 2009

More Business News

- Latino grocery keeps growing
- turning A crisis into opportunity
- Seniors may have vehicles checked for safety today
- Fall, early winter bookings pick up at mountain resorts
- Analysts suggest Adobe systems may see rival offers for Utah's Omniture
- Vision Bankcard to acquire stake in Centennial Bank of Ogden
- Junior League to host Touch a Truck festival

Utah geothermal plant runs into cold-water problem

Geothermal plant's cold water means it buys nearly as much power as it makes.

By Steven Oberbeck

The Salt Lake Tribune

Updated: 09/18/2009 08:07:32 AM MDT

Raser Technologies Inc. long has boasted its new Hatch geothermal power plant near the west-central Utah city of Beaver would launch a new era of energy production -- one in which electricity would be produced from low-temperature underground water that wasn't viewed as hot enough to produce power.

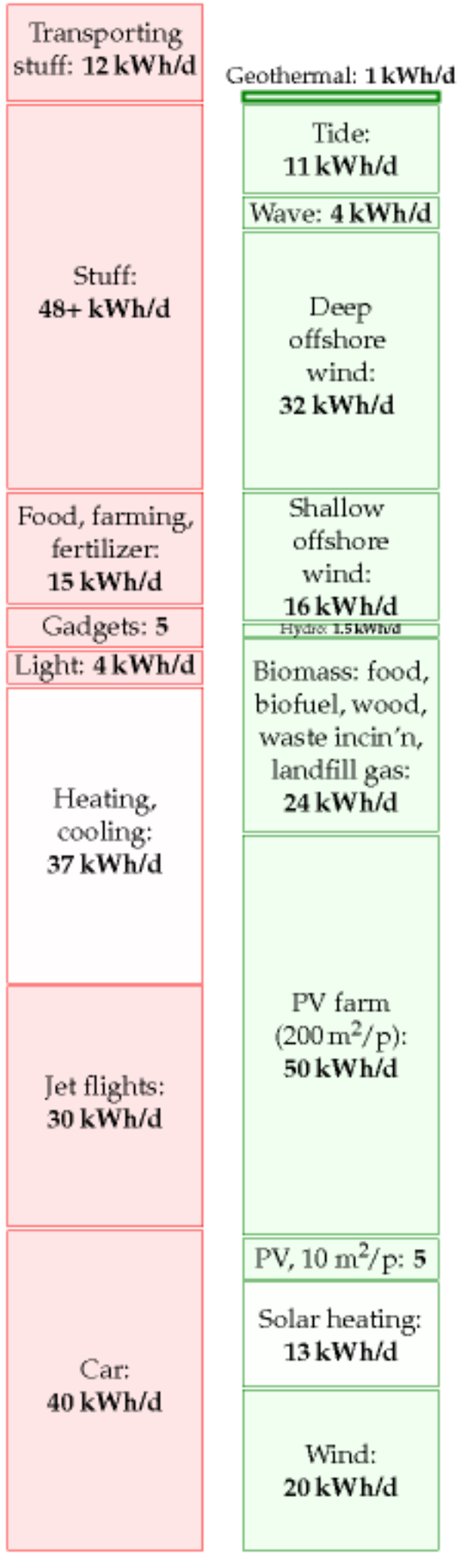
Yet six months after Raser flipped the switch on the plant and began generating power, the company is buying almost as much electricity to keep the place running as the plant is producing.

The problem: The plant can't operate at full capacity because its production wells are producing geothermal water that isn't hot enough, even though its temperature is higher than the 180 degrees Raser initially said it would need.

Click photo to enlarge

Pipefitter Rod Hooley prepare hot water... (Steven Oberbec Lake Tribune)

Still to come
on the red stack:
- industry,
- road building,
- 'defence',
- hospitals, ...



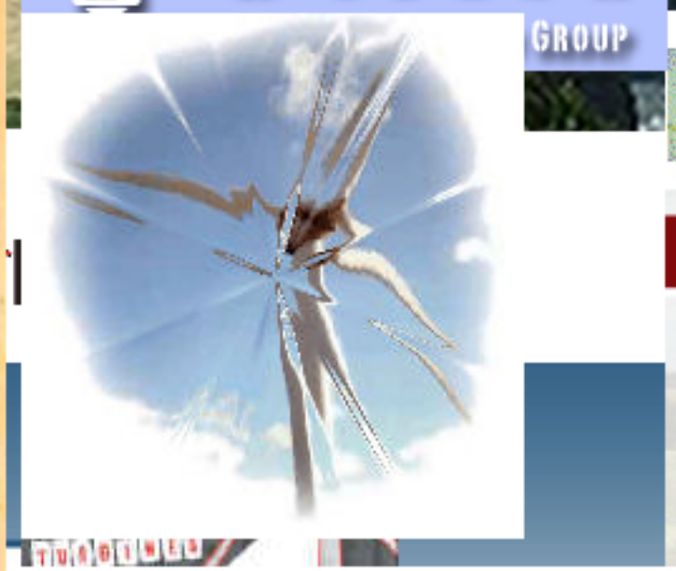
It would be very difficult to live on our own renewables

- at least, as we currently live

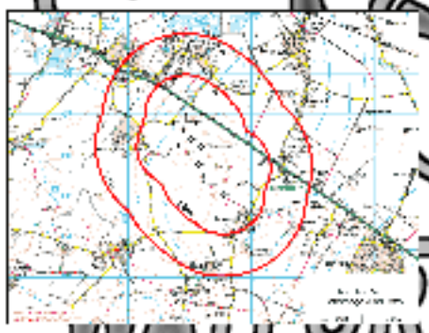
www.withouthotair.com

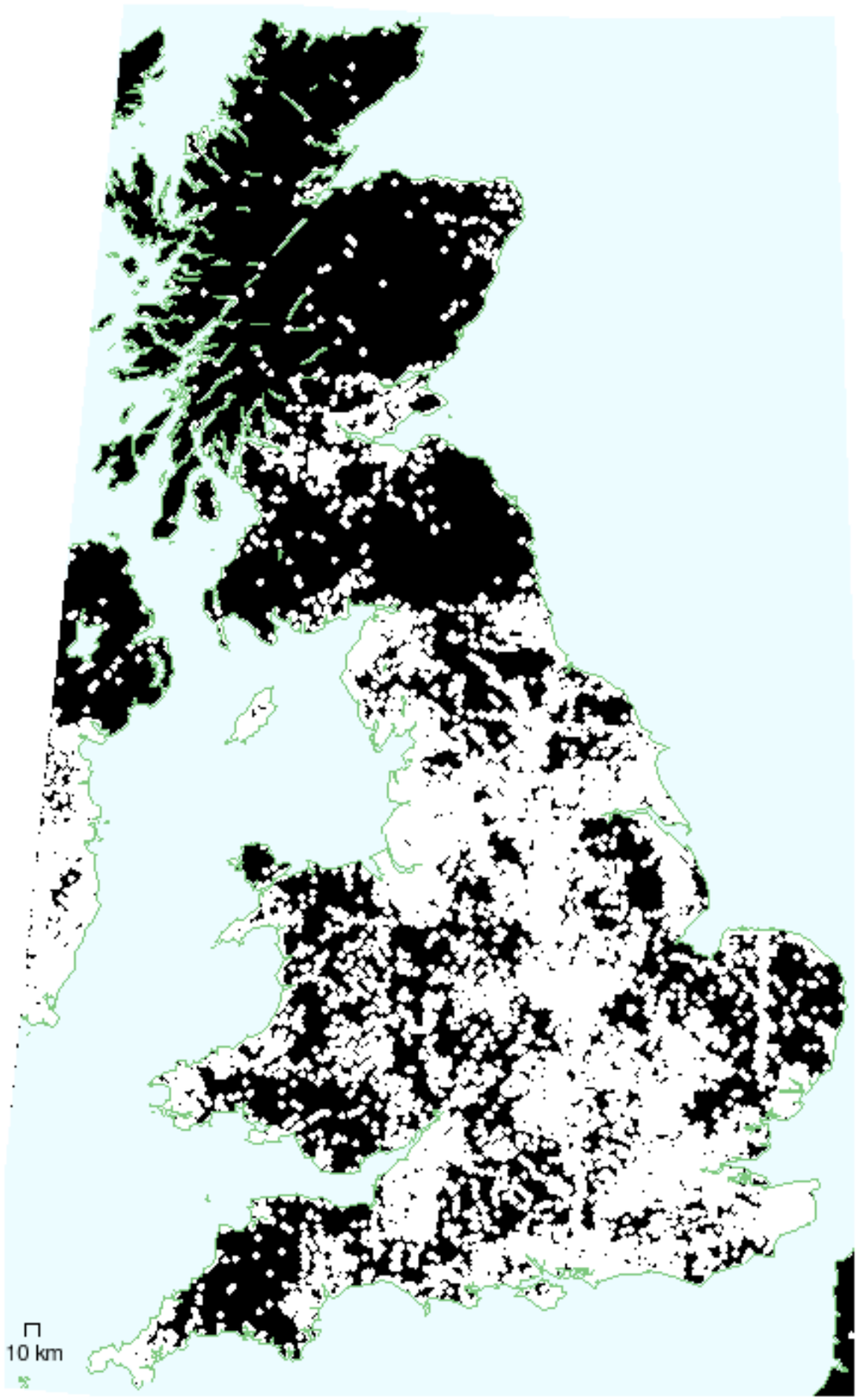
A consultation exercise in full swing

jokes/87g



www.
stopbeningtonwindfarm
.co.uk




10 km

Save Our Scenery -

Protecting Our Heritage Coastline

BEFORE

AFTER

FROM LLANDUDNO PROMENADE

FROM COLWYN BAY PROMENADE

saveourscenery.com

Printer friendly
Send to a friend
Tag/Bookmark

News

Giant Wind Farm Off English Coast Pits Town Against Shell, E.ON

Graveney was the site of the last combat on English soil when British forces battled a downed German bomber crew in 1940. Now the village is fighting a new enemy: the world's biggest wind farm. The local council, acting on behalf of the town's 473 residents, refused to permit a substation for the $1.5 billion London Array, which would put 271 wind turbines in the estuary of the River Thames. Royal Dutch Shell Plc and E.ON AG plan to bring power cables ashore near Graveney. "They say this is the only place they could put it — that's rubbish," said retiree George Schneider, 73, strolling on Saxon Shore Way, a rambling route across the coastal plain. "Why use a green-field site when there are other places?"

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search news

are springing up on land-based
some are even becoming tourist
– proposals for offshore farms are
popular.

Estate has
ible 18
d the UK
hough each
ds to gain

ccepted by
others are
tink.

n strong
:o schemes
ms in the
and off Portstewart, near the
seway in Northern Ireland.

Surfers are worried about the impact

About News Opinions Library Press

News

Wind farm 'a threat to our airport'

Southend Airport has raised serious objections to plans to build a new wind farm – even though the turbines would be nearly 15 miles to the n experts say a wind farm next to the defunct nuclear power station, at Br air traffic control issues and might even interfere with radar. Airport mar Alistair Welch raised the concerns at a public inquiry which is being helc

June 22, 2007 in Echo

Southend Airport has raised serious objections to plans to build a new wind farm – even would be nearly 15 miles to the north.

Job creation

In Porthcawl in south Wales, a pressure group called SOS Porthcawl has been set up to oppose plans for a wind farm four miles out to sea.

The proposal is for 30 turbines on Scarweather Sands, each 453 feet high.

It could provide enough energy for more than 40,000 homes.

The production of the turbines could also create 130 jobs – they are made in Wales at Bangor and more could be produced at Port Talbot.

Tourism

But SOS Porthcawl says the turbines will be noisy and visible from beauty spots, which would deter tourists.

Protesters target wind farm plans

Plans of how the wind farm will look are on display

Porthcawl is a popular spot for surfers

Local people opposing plans to build one of the UK's big
south Wales coast met on Friday. Residents in Porthcaw
to highlight their opposition to the proposed 30-turbine
Sands.

SOS Porthcawl was set up by campaigners in the town v
say the wind farm will adversely affect the holiday reso
which attracts surfers and tourists from all over the UK
demonstration coincides with a public consultation into
project by developers United Utilities Green Energy.
Four-times British surf champion, Simon Tucker said the
was a lot of feeling against the proposals within the tow
"This demonstration is to ask the developers not to dest
the very environment they claim they are trying to prote
he said. Mr Tucker said the turbines, which are taller th
the Statue of Liberty in New York, will destroy the pano
views and also have an impact on the sea.

"The turbines will change the shape of the sandbanks a
the waves," he said. "If the waves are changed and peop
sport because of the turbines then the town is going to
company behind the £100m scheme say the turbines, wh
sea level, will generate enough power for 86,000 homes
The site, which is to the west of Porthcawl, is approxima
the nearest household.

Project - Is This A New Klondyke?

y Herald (linked above) talks about the views
and disappearing as we used to know them - vast
st as they had been for hundreds of years and
n industrial scene. As we watch the first massive
aithness and Sutherland coast are we watching
other aspect of our scenery - the coastal views?
another hazard for fishing boats and vessels to
view now of anyone on the east of Caithness are
thers as we face up to rising oil prices and the
. We already see oil rigs with in view. Will wind
ut at sea than on our hills and mountains?

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Last Updated: Friday, 28 May, 2004, 16:58 GMT 17:58 UK

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Fishermen oppose wind farm plans

Hundreds of fishermen gathered in the Wash to protest against plans to build offshore wind turbines.

The men from Boston, Skegness and King's Lynn are unhappy at government proposals to erect 250 wind turbines in the Greater Wash.

If it goes ahead, the facility would be part of one of the largest wind farms in the world.

Planning permission has already been granted for 60 turbines on two sites off the south Lincolnshire coast.

Hundreds of turbines could be built about five miles off the coast

Project 'impractical'

Andy Roper, who organised the protest, emphasised the fishermen's livelihoods are being threatened.

From The Times

November 23, 2002

Winds of change will mean giant sea turbines

By Anthony Browne, Environment Editor

DOZENS of wind farms, each with hundreds of turbines up to 500ft high, are to be given the go-ahead off the coast between Scotland and Wales, around the Wash in East Anglia and in the Thames Estuary.

Yesterday's announcement was welcomed by some environmental groups; others have given warning that it will ruin views and damage sea life. Fishermen have said that they will be forced out of business.

Brian Wilson, the Energy Minister, said: "In theory, these areas could source enough electricity to power the whole of Britain, albeit intermittently. There is no doubt

From The Times

February 4, 2008

Wind farms 'a threat to national security'

Magnus Linklater and Dominic Kennedy

Ambitious plans to meet up to a third of Britain's energy needs from offshore wind farms are in jeopardy because the Ministry of Defence objects that the turbines interfere with its radar.

The MoD has lodged last-minute objections to at least four onshore wind farms in the line of sight of its stations on the east coast because they make it impossible to spot aircraft, *The Times* has learnt. The same objections are likely to apply to wind turbines in the North Sea, part of the massive renewable energy project announced by John Hutton, the Energy Secretary, barely two months ago. They would be directly in line with the three principal radar defence stations, Brizlee Wood, Saxton Wold and Trimingham on the Northumberland, Yorkshire and Norfolk coasts.

Wind power 'a security ris

02 November 2007 08:15

Defence chiefs threw the future of East Anglia's wind energy industry into confu last night after claiming that wind turbin could be a threat to national security.

Experts say the MoD now objects to abou 50pc of applications to build onshore wir turbines because of concerns they affect performance of military radar.

Carbon Trust

No constraints

Add hard constraints

Levelised costs of offshore wind development at available sites, £/MWh (2008)[1]

- 80
- 80-87
- 87-94
- 94-100
- 100-104
- 104-111
- 111-118
- >118
- UK continental shelf boundary

Add soft constraints

All constraints

Annual mean wind speed

at 25m above ground level [m/s]

Sensitivity ratings within tetrad:

4 high	(5421)
3 high	(1411)
2 high	(1964)
1 high	(1573)
4 medium	(4109)
3 medium	(482)
2 medium	(785)
1 medium	(727)
All low/unknown	(5715)

> 10
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
< 5

125 km

Transporting stuff: **12 kWh/d**

Stuff: **48+ kWh/d**

Food, farming, fertilizer: **15 kWh/d**

Gadgets: **5**

Light: **4 kWh/d**

Heating, cooling: **37 kWh/d**

Jet flights: **30 kWh/d**

Car: **40 kWh/d**

~~Geothermal: **1 kWh/d**~~

Tide: **11 kWh/d**

~~Wave: **4 kWh/d**~~ too expensive!

~~Deep offshore wind: **32 kWh/d**~~ not near my radar!

~~Shallow offshore wind: **16 kWh/d**~~ not near my birds!

~~[illegible]~~ not in my valley!

~~Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**~~ not in my countryside!

~~PV farm (200 m^2/p): **50 kWh/d**~~ too expensive!

~~PV: 10 m^2/p: **5**~~ too expensive!

~~Solar heating: **13 kWh/d**~~ not on my street!

~~Wind: **20 kWh/d**~~ not in my back yard!

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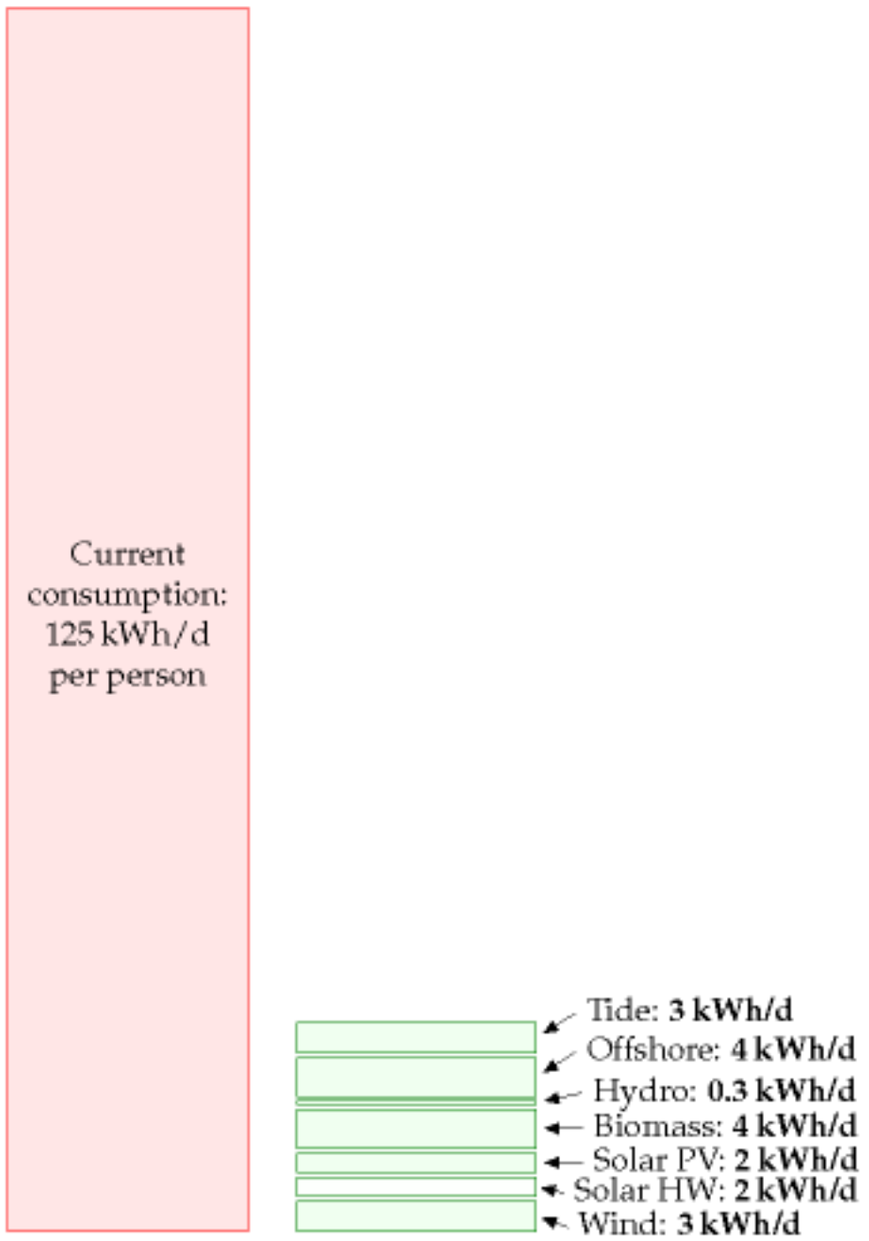
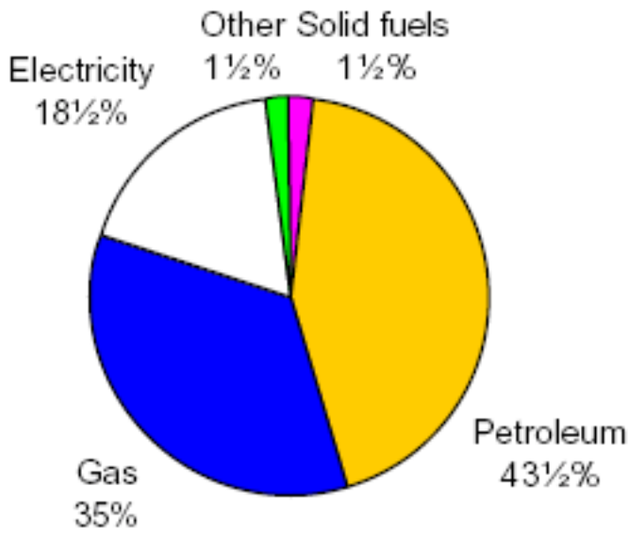
after the great British consultation exercise...

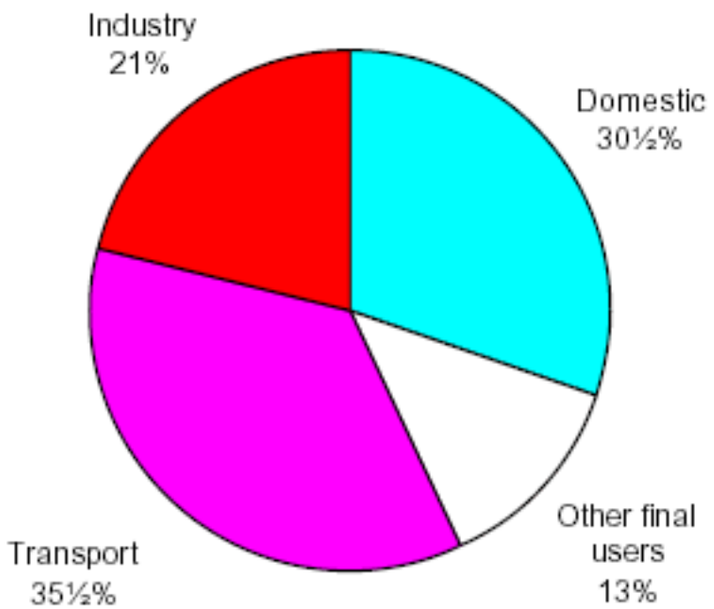


This would be a 15-fold increase of renewables

Average power consumption, UK: 125 kWh/d/p



2004



www.dti.gov.uk

'primary consumption'

125 kWh/day (Europe)

250 kWh/day (USA)

(doesn't include imports,
nor solar energy in food)

For CO_2 pollution, divide by 10:

100 kWh/day $\simeq$ 10 tonnes CO_2/yr

Conclusions - part I

A country like Britain

can't live on

its own renewables

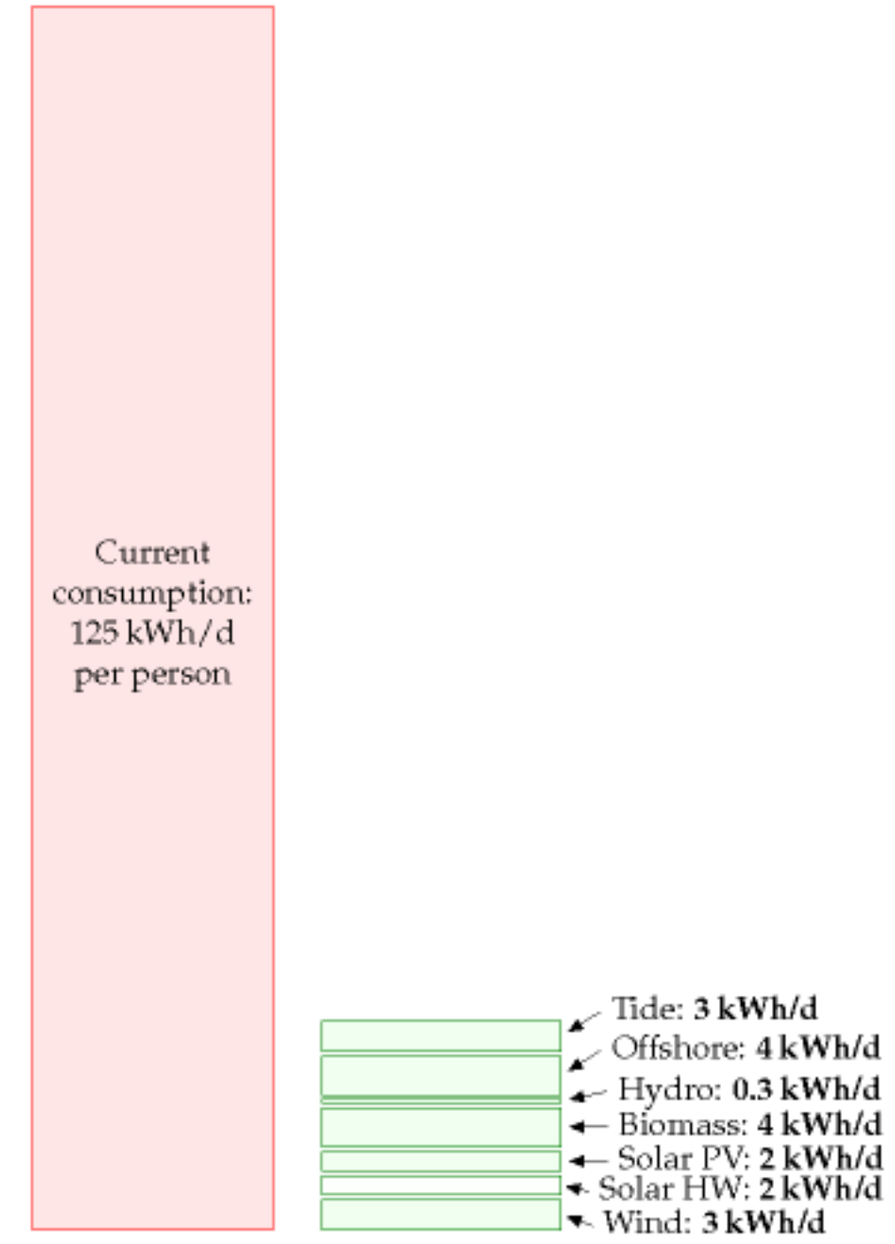
- at least,

not as we currently live

To make a difference,

renewables have to be

country-sized



Renewables are diffuse

Power per unit land area	
Wind	$2\,\mathrm{W/m^2}$
Offshore wind	$3\,\mathrm{W/m^2}$
Tidal pools	$3\,\mathrm{W/m^2}$
Tidal stream	$8\,\mathrm{W/m^2}$
Solar PV panels	5–$20\,\mathrm{W/m^2}$
Plants	$0.5\,\mathrm{W/m^2}$
Solar chimney (Spain)	$0.1\,\mathrm{W/m^2}$
Concentrating solar power (desert)	15–$20\,\mathrm{W/m^2}$
Ocean thermal	$5\,\mathrm{W/m^2}$
Rain-water (highlands)	$0.24\,\mathrm{W/m^2}$
Rain-water (lowlands)	$0.02\,\mathrm{W/m^2}$

- To make a difference, renewable facilities have to be country-sized

Block

News

News
England
Northern Ireland
Scotland
Wales
International
RSS feeds

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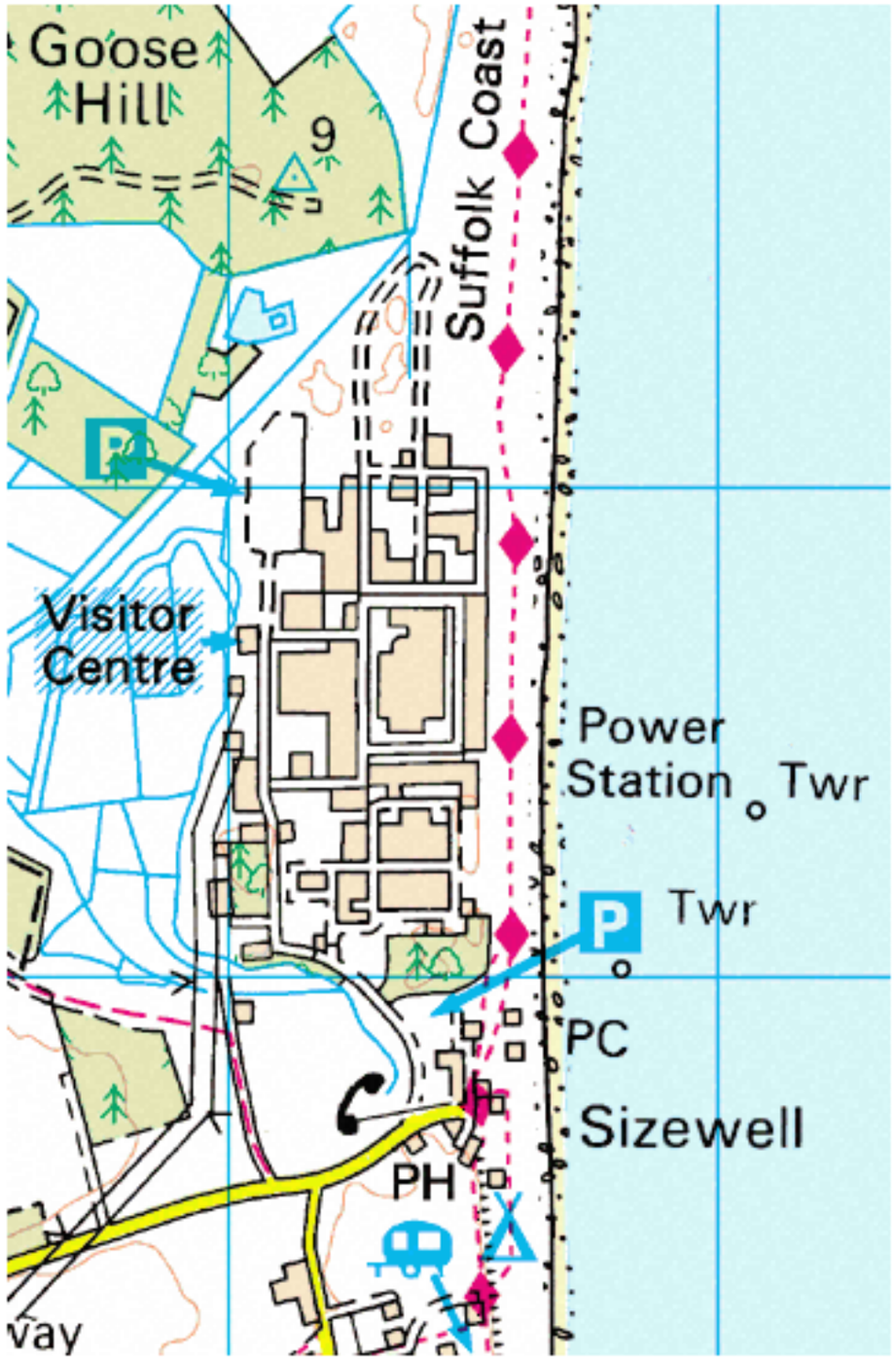
No green light for Severn barrage

Last modified: 01 October 2007

Europe's most dynamic estuary will be destroyed by the construction of a barrage across the Severn while other less striking measures would cost less and could do more to cut carbon emissions.

"other less striking measures"?

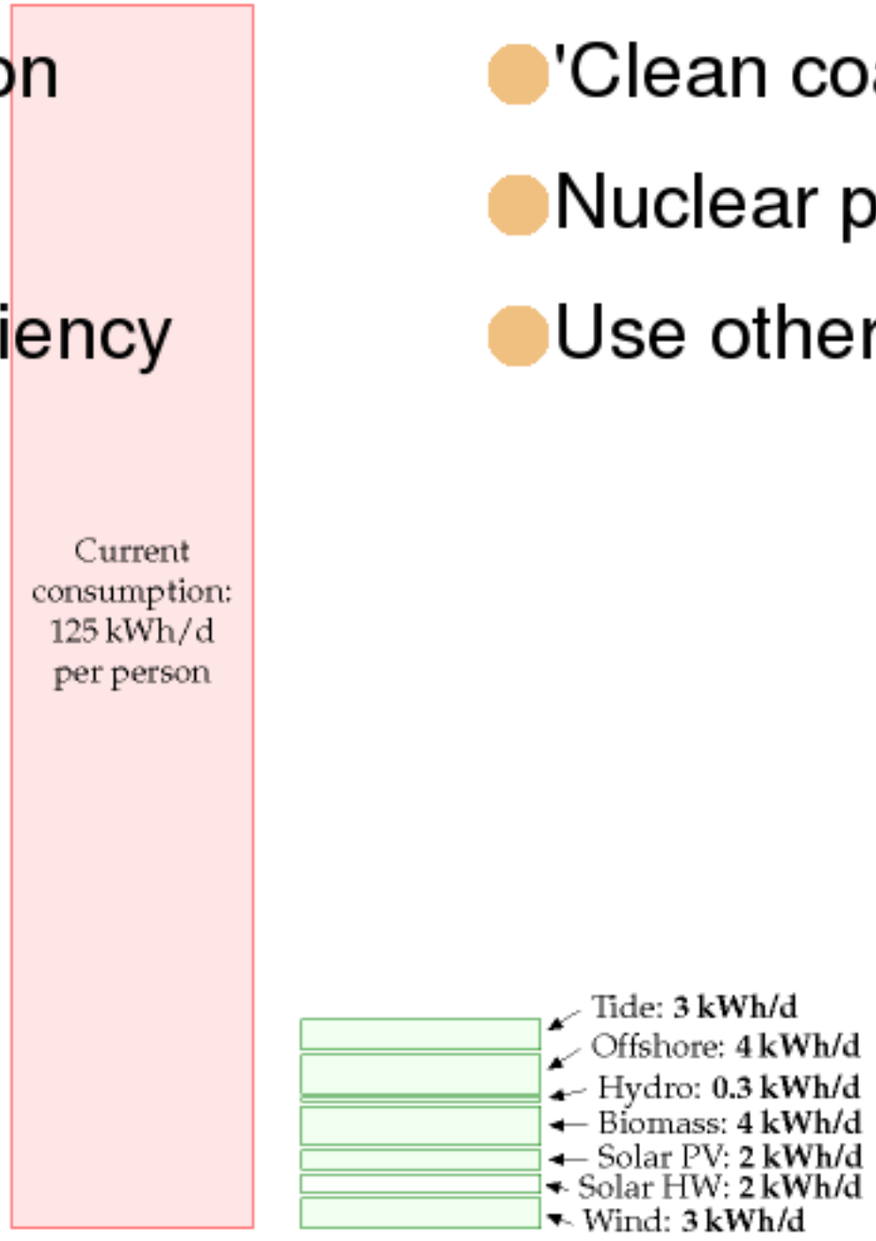
To make a difference, renewable facilities have to be country-sized



Nuclear	
Fission	$1000\ \mathrm{W/m^2}$

Part II: How to make an energy plan that adds up

- Demand-side
  - Reduce population
  - Change lifestyle
  - Technology, efficiency
- Supply-side
  - 'Clean coal'
  - Nuclear power
  - Use other countries' renewables



Warrior / Efficiency for transport

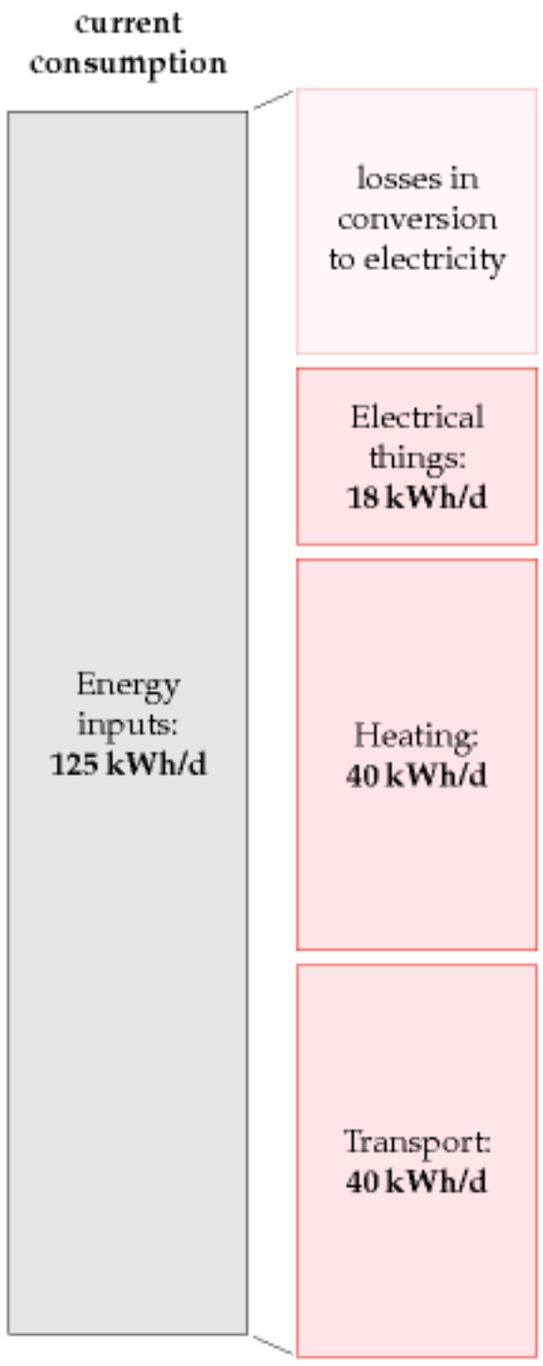
Change lifestyle?

A Mitsubishi Warrior, yesterday

Some people demand the right to commit Amazingly brave acts of off-road driving

EFFICIENCY

- Cartoon Britain, 2008



Efficient transport

Have small frontal area per person

Have small weight per person

Convert energy efficiently

Go slowly

Go steadily

Average UK car uses

80 kWh per 100 person-km (1 person)

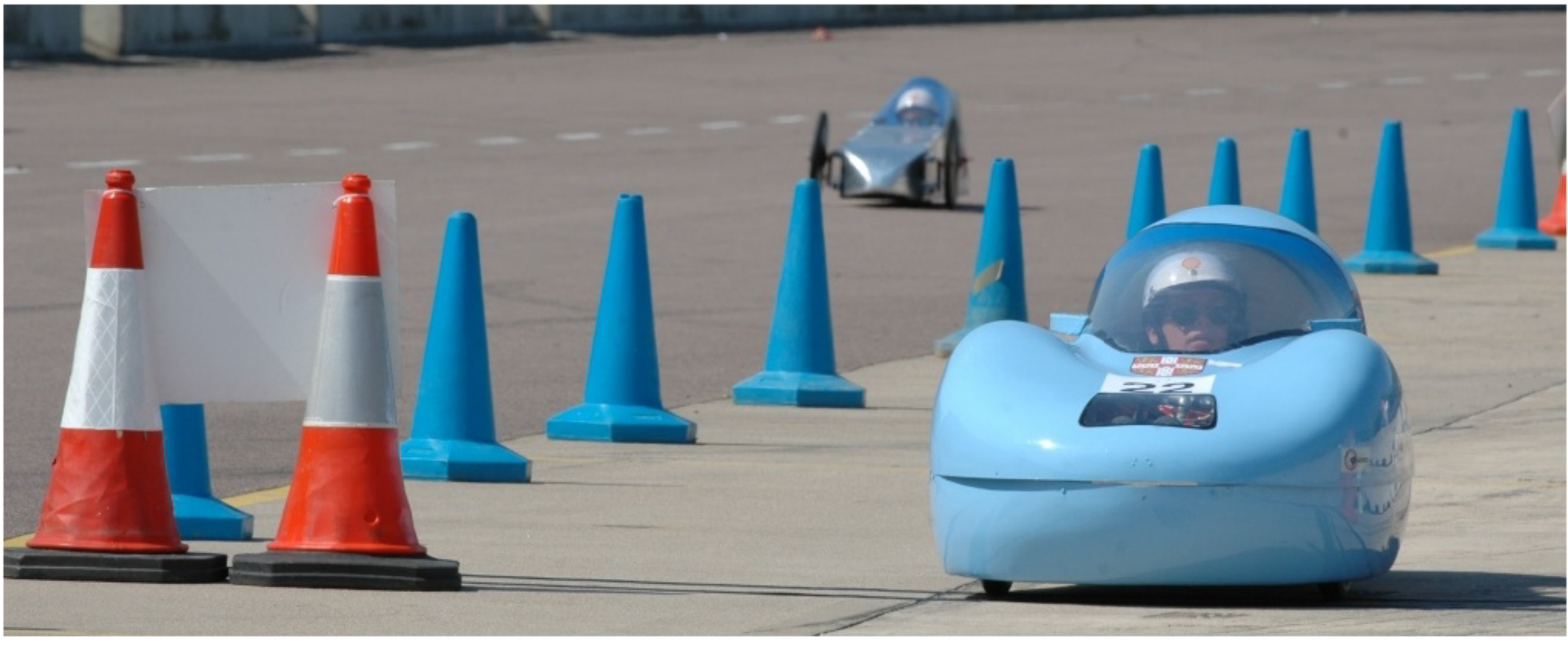
How can this consumption be reduced?

1 kWh per 100 person-km (3 people)

6 kWh per 100 person-km average (electric)

3 kWh per 100 person-km (electric) if full

Eco-car



1.3 kWh per 100 person-km (takes 1 teenager)

[2200 mpg]

at 15 mph

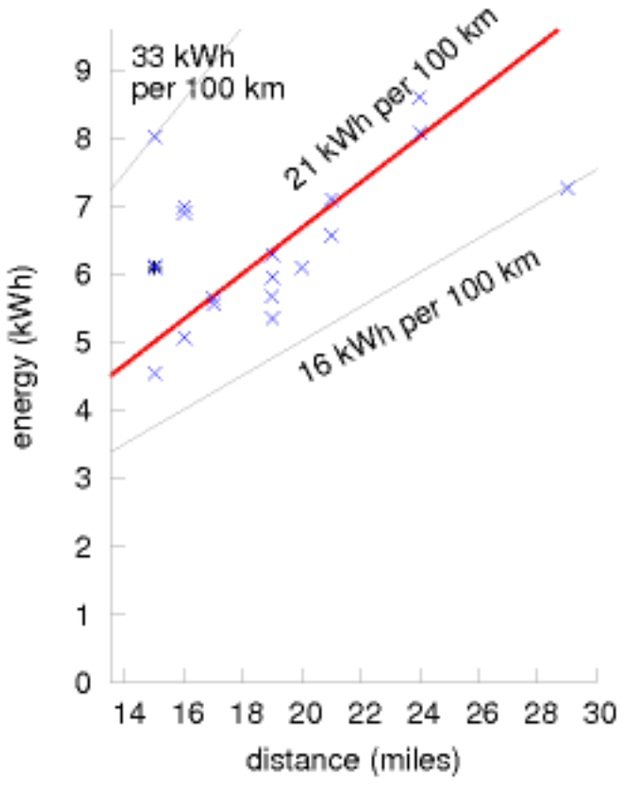
http://www.teamcrocodile.com/

5-8 kWh per 100 km at 30 mph

Electric cars

21 kWh per 100 km (solo)

equivalent to 125 miles per gallon



data from Kele Baker

G-Wiz

6 kWh per 100 km

Th!nk Ox

20 kWh per 100 km

UK's first four-seater all electric production car

Thursday, 30 Apr 2009 09:03

The UK's first all electric four-seater car is available to buy from today, the Electric Car Corporation Plc (ECC) have announced.

The launch coincides with the government's announcement to support and subsidise electric car use, and their "commitment to make the UK a world leader in producing and exporting electric cars".

The motor, a Citroën C1 'ev'ie', is the first 4-seat car to be all electric, with a range of 60-70 miles when fully charged and with top speeds of around 60mph.

The C1 can be fully charged in 6-7 hours from a domestic 13 amp socket at a cost of around 90p, making it an ideal city car for either professional or domestic use.

18 kWh per 100 km (?)

Tesla, Lightning

11 kWh per 100 km

www.lightningcarcompany.co.uk

15 kWh per 100 km

www.teslamotors.com

Loremo

Aptera

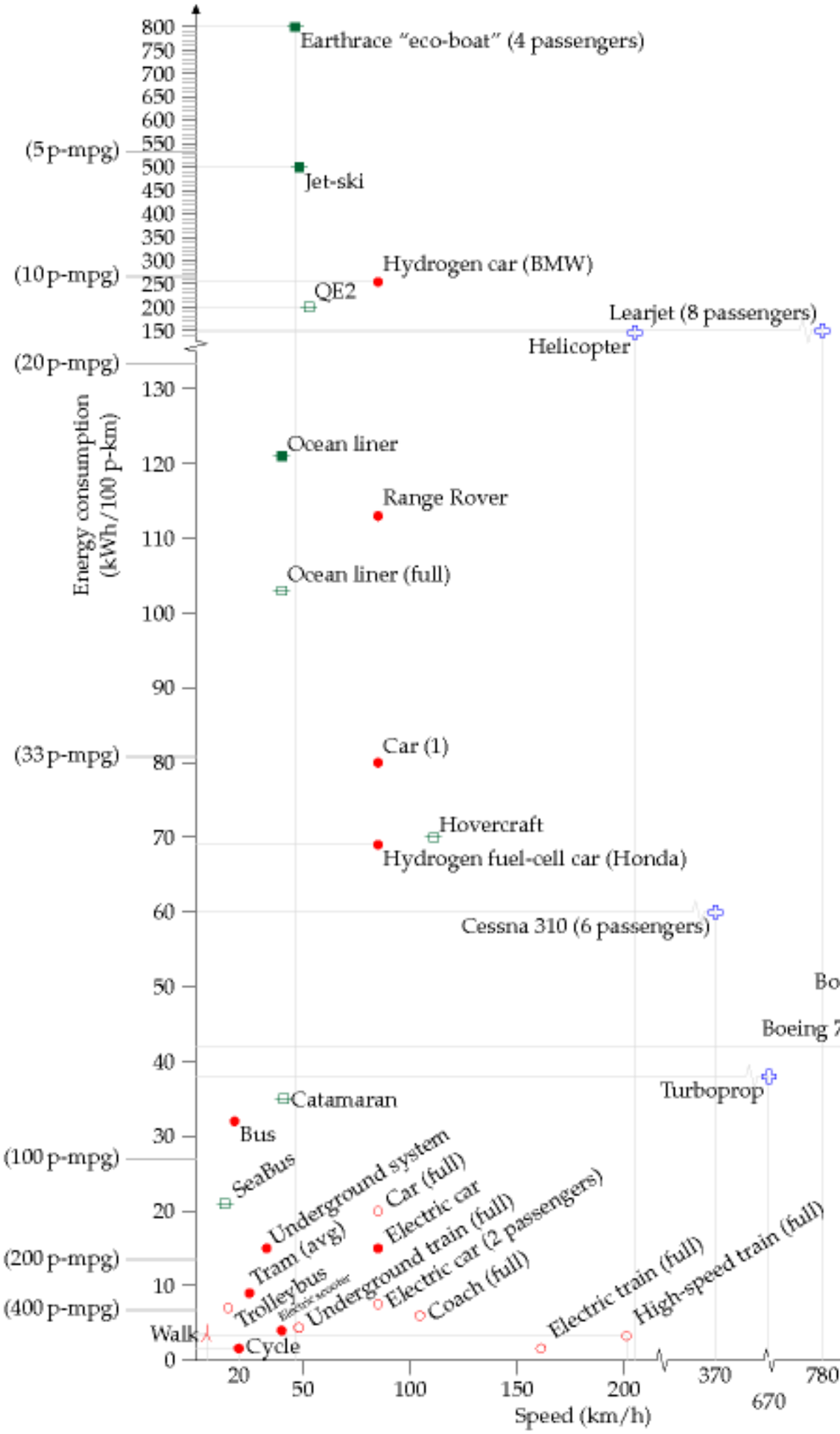
TREV

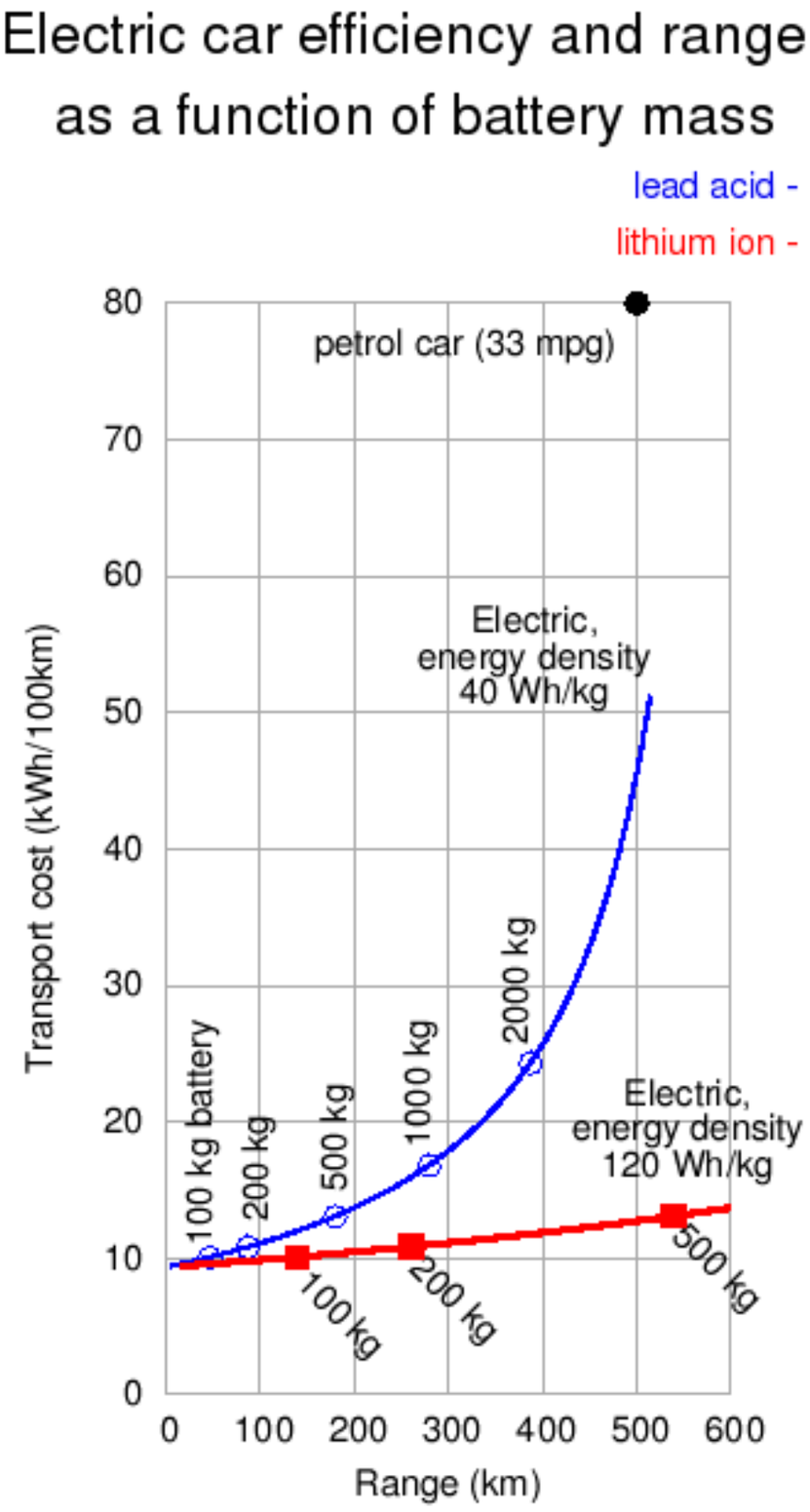
6 kWh per
100 km

Electric scooters

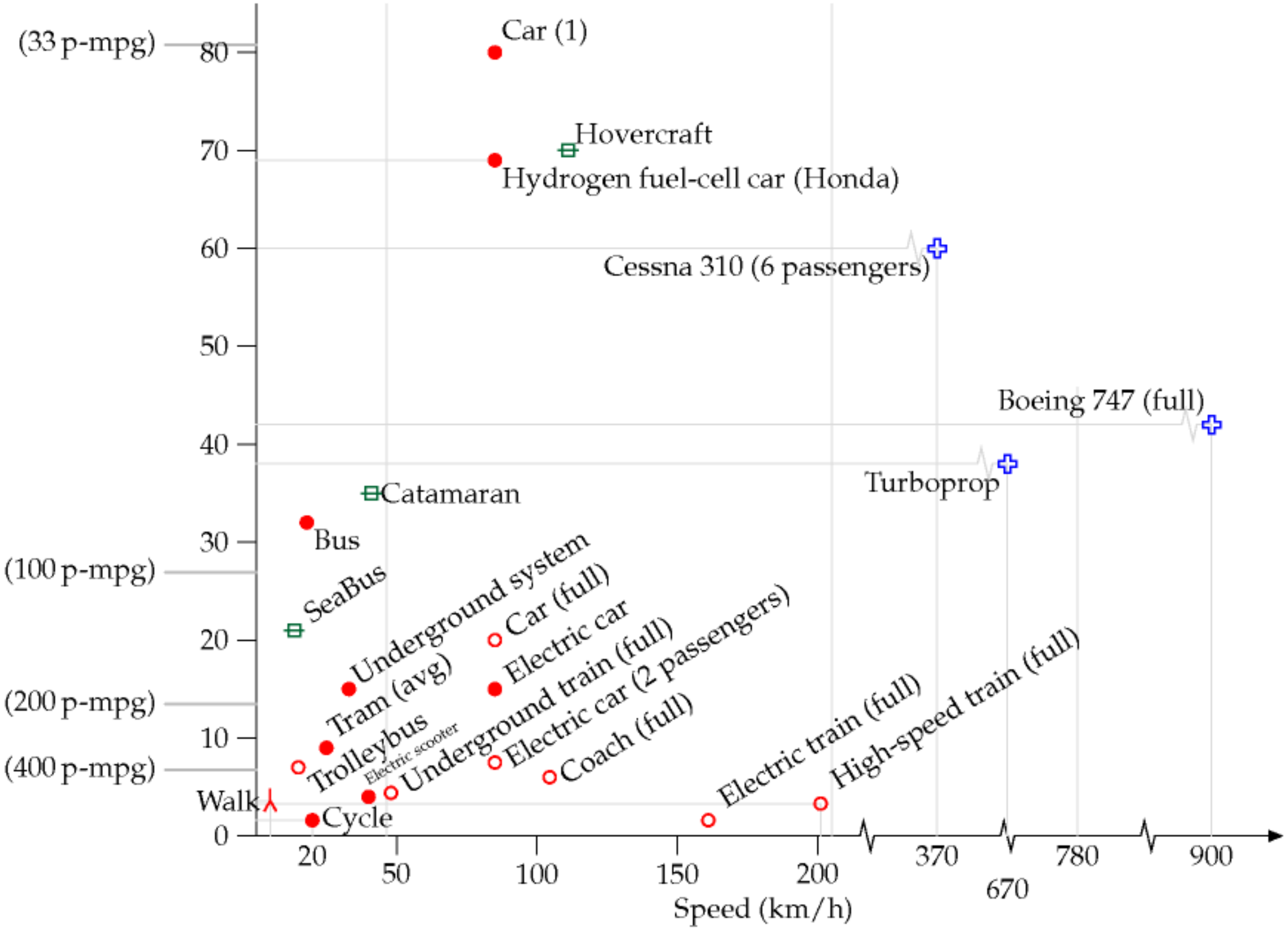
3 kWh per 100 km

http://www.vectrix.com/

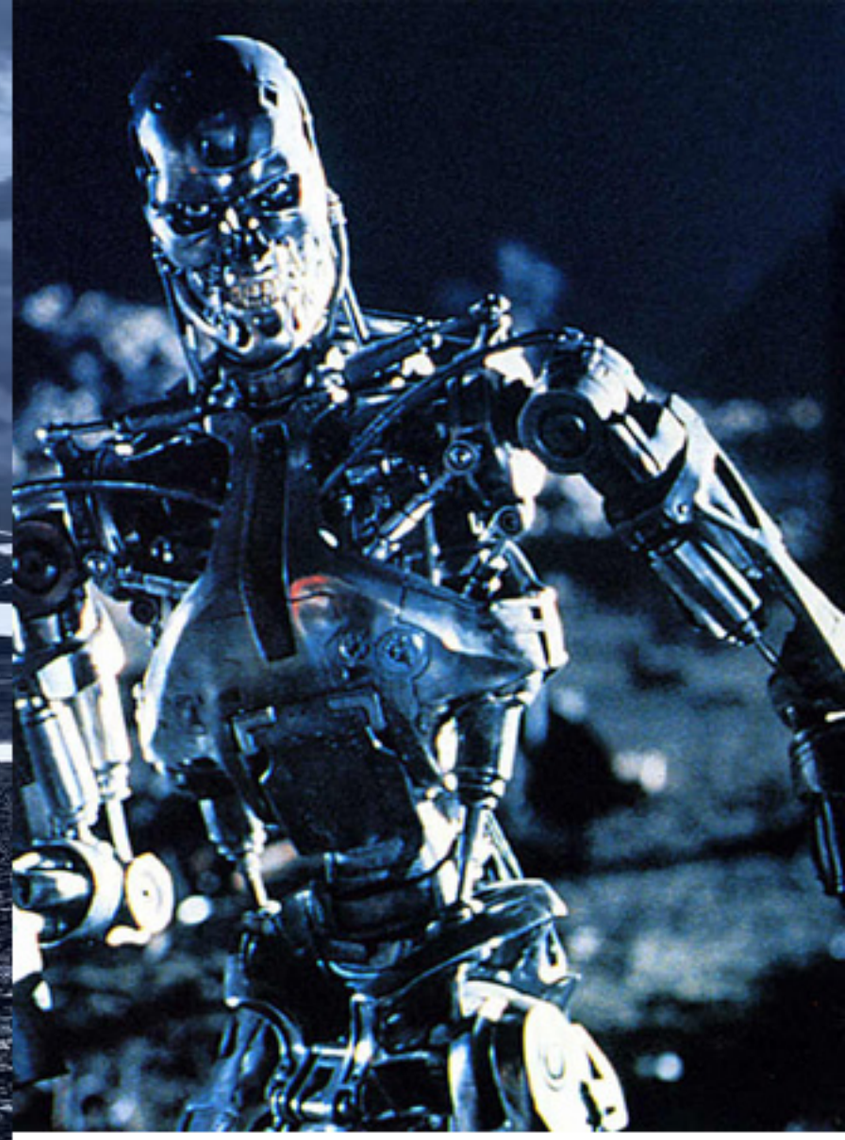

Earthrace "eco-boat" (4 passengers)
(5 p-mpg)
Jet-ski
Hydrogen car (BMW)
(10 p-mpg)
QE2
Learjet (8 passengers)
Helicopter
(20 p-mpg)
Energy consumption (kWh/100 p-km)
Ocean liner
Range Rover
Ocean liner (full)
(33 p-mpg)
Car (1)
Hovercraft
Hydrogen fuel-cell car (Honda)
Cessna 310 (6 passengers)
Boeing 747
Boeing 747 (full)
Turboprop
Catamaran
Bus
(100 p-mpg)
SeaBus
Underground system
Car (full)
Tram (avg)
Electric car
(200 p-mpg)
Trolleybus
Underground train (full)
Electric car (2 passengers)
(400 p-mpg)
Coach (full)
Electric train (full)
High-speed train (full)
Walk
Cycle
Speed (km/h)


Electric car efficiency and range as a function of battery mass
lead acid -
lithium ion -
petrol car (33 mpg)
Electric, energy density 40 Wh/kg
Electric, energy density 120 Wh/kg
100 kg battery
200 kg
500 kg
1000 kg
2000 kg
100 kg
200 kg
500 kg
Transport cost (kWh/100km)
Range (km)

Energy consumption (kWh per 100 passenger-km)



Plug-in hybrids



Plug-in hybrids

25 kWh per 100 km

(running on electric power alone)

'Can't be done'

Lisbon's electric car deal leads way

By Peter Wise
Published: November 24 2008 02:00 | Last updated: November 24 2008 02:00

Portugal is to become the first European country to be supplied with electric cars by Renault and Nissan after signing an agreement to create a national network for zero-emission vehicles within three years.

The plan highlights Portugal's commitment to invest in clean energy, in spite of concerns that the global financial crisis is deterring governments from implementing ambitious European Union plans to fight global warming.

Under the agreement, finalised with the Franco-Japanese carmaking alliance over the weekend, 320 vehicle charging locations will be operational across Portugal by 2010, growing to 1,300 by the end of 2011.

Companies and motorists who buy electric cars will be exempt from road and other vehicle taxes and individuals will qualify for income tax benefits of up to €800, said José Sócrates, prime minister.

The government will also require 20 per cent of public sector vehicle purchases to be zero-emission.

Peter Wise, Lisbon

Free parking for electric cars axed - for being too successful

David Williams, Motoring Editor
24.06.08

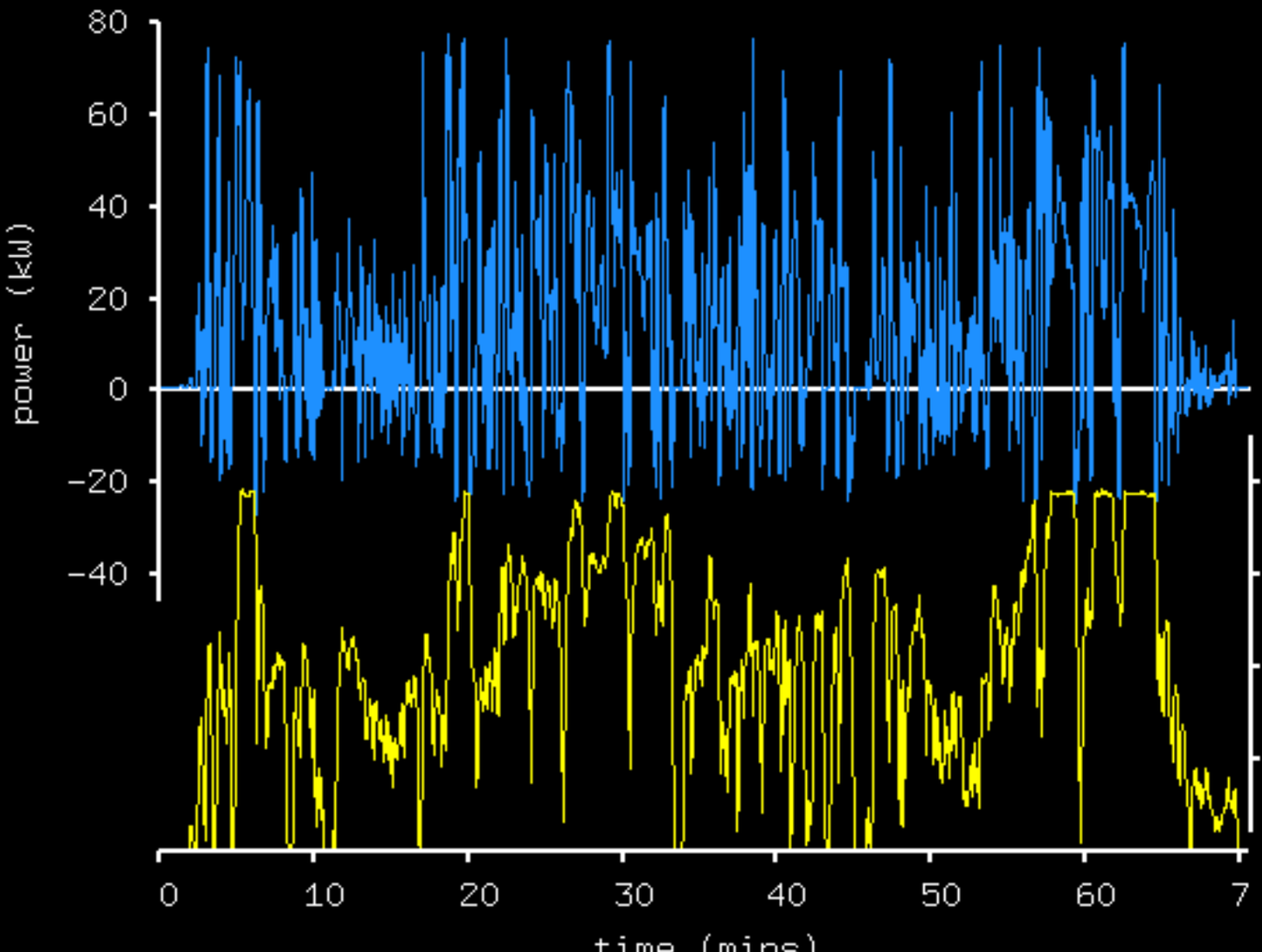
A pioneering scheme that rewards owners of electric vehicles with free parking is being scrapped – because it works too well.

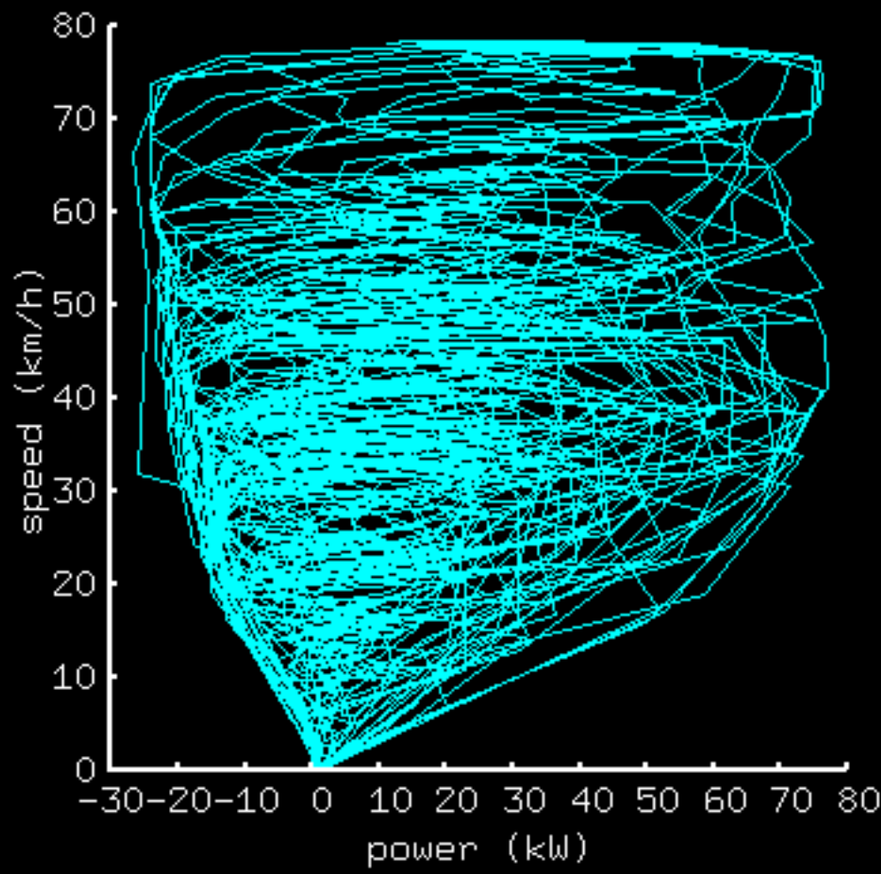
Charging time: owners of electric cars like this Nice M
park in the City of London

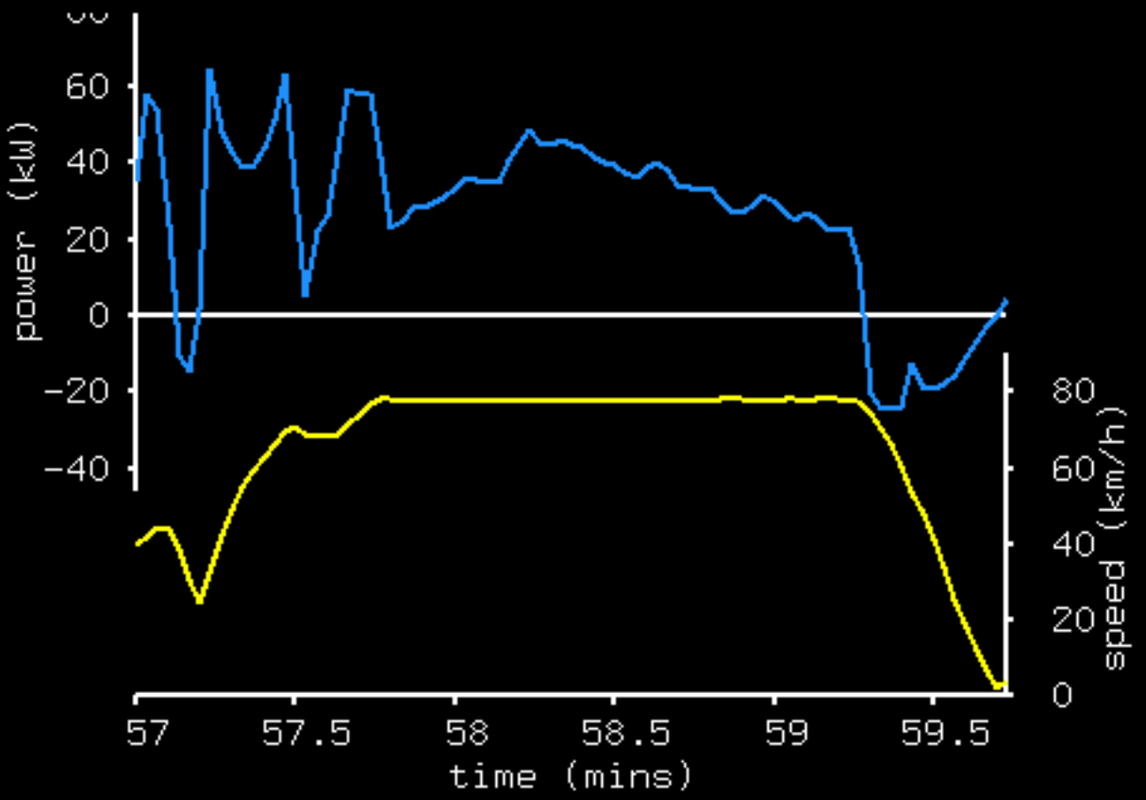
Since 2001, the City of London has issued free roadside parking passes to nearly 500 drivers of the zero-emission cars in a bid to encourage other people to buy one. It has

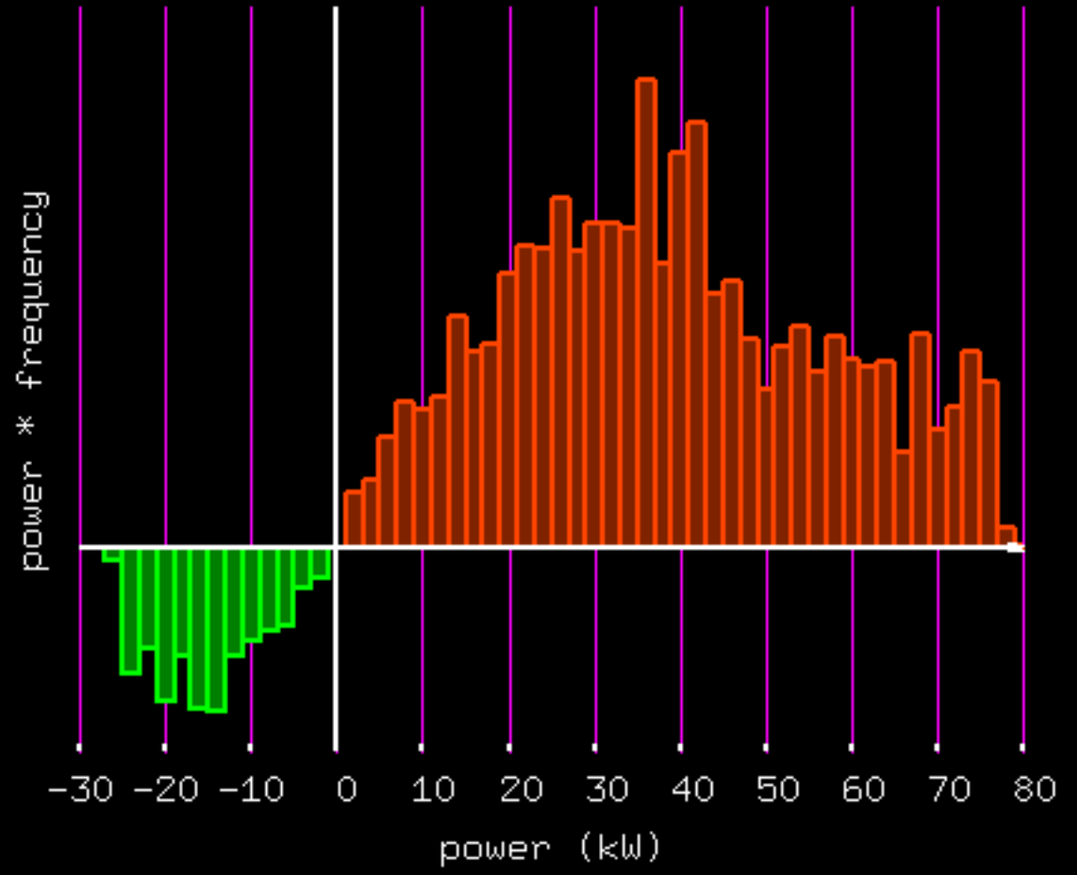
Modec


www.modecZEV.com
MODEC
www.modecZEV.com
Modec
Zero Emission Vehicles
Emission Vehicle


power (kW)
80
60
40
20
0
-20
-40
speed (km/h)
80
60
40
20
0
10
20
30
40
50
60
7
time (mins)


speed (km/h)
80
70
60
50
40
30
20
10
0
-30 -20 -10 0 10 20 30 40 50 60 70 80
power (kW)

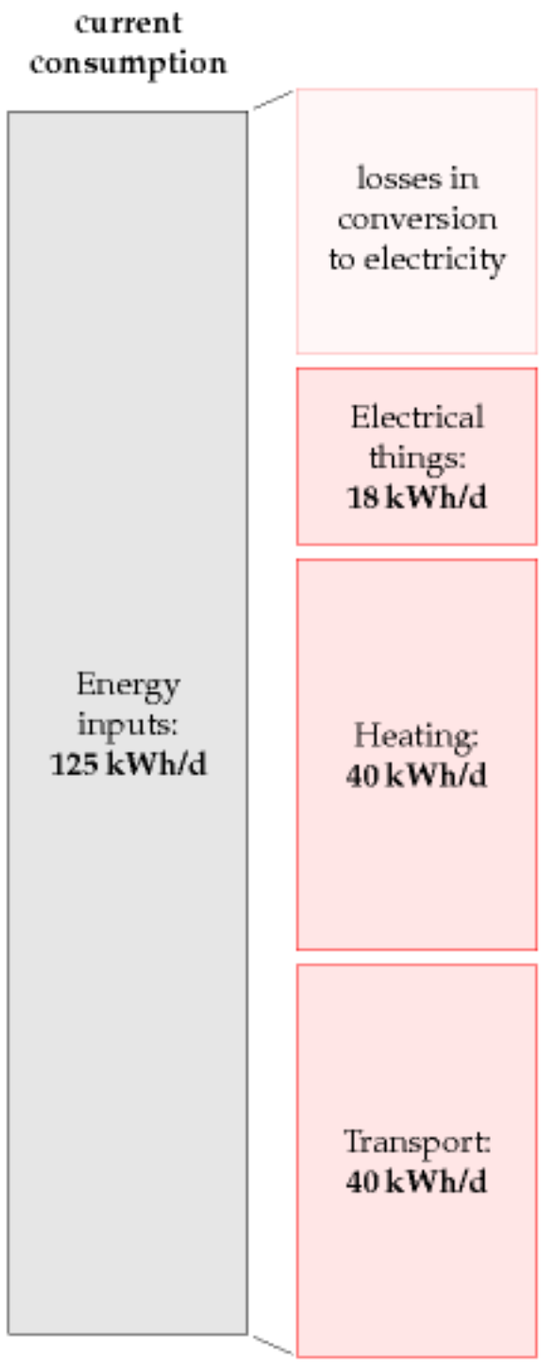

power (kW)
60
40
20
0
-20
-40
speed (km/h)
80
60
40
20
0
57
57.5
58
58.5
59
59.5
time (mins)


power * frequency
-30 -20 -10 0 10 20 30 40 50 60 70 80
power (kW)


17

EFFICIENCY

- Cartoon Britain, 2008



Efficiency for heating

- Reduce temperature difference
  - Turn the thermostat down
- Reduce leakiness
- Increase CoP of heat-creation

← Leakiness: 8 kWh/d/°C

$$\underset{\text{(kWh/d)}}{\boxed{\text{Heat loss}}} = \underset{\text{(kWh/d/°C)}}{\text{Leakiness}} \times \underset{\text{(°C)}}{\text{Average temperature difference}}$$

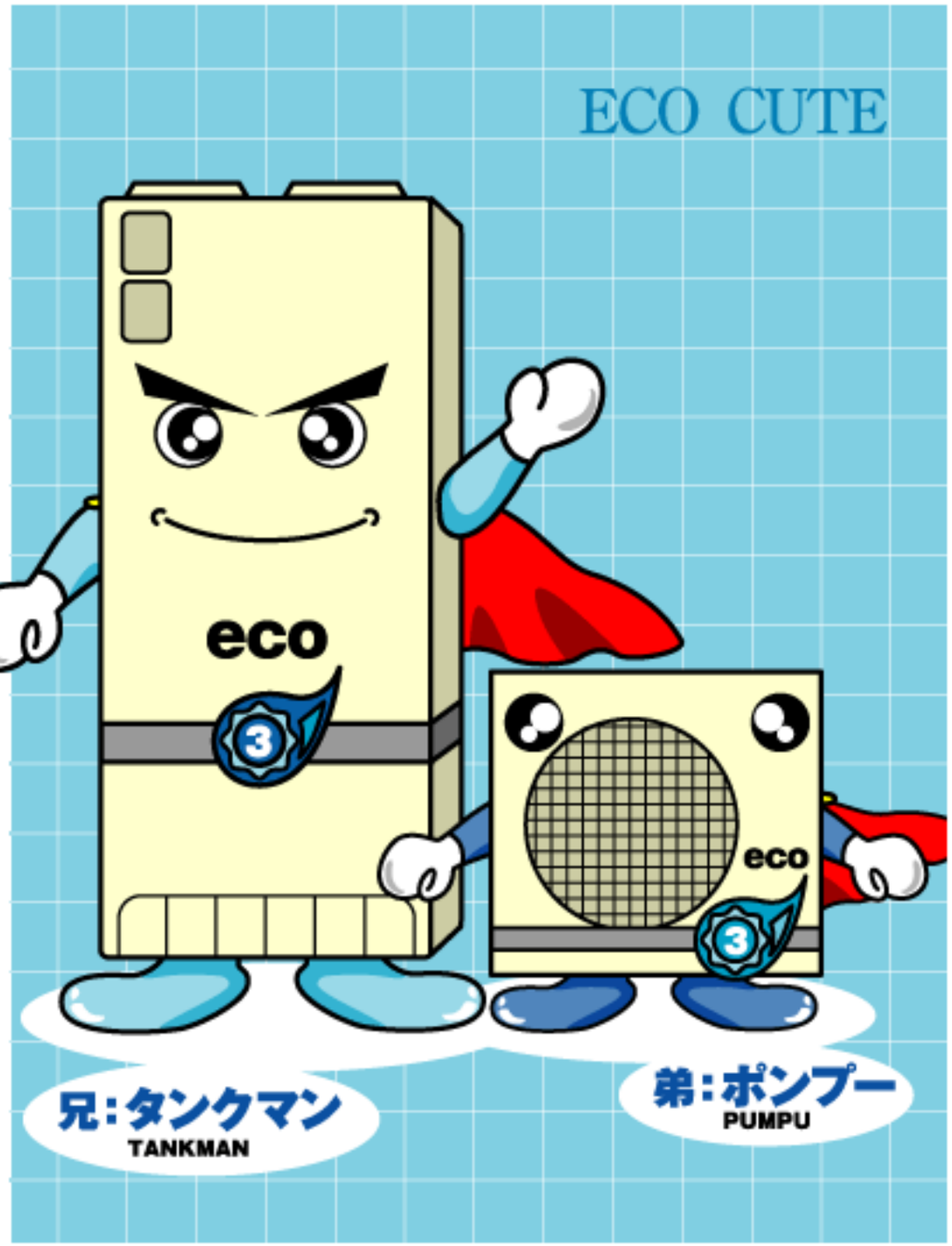
$$\text{Power required} = \boxed{\text{Heat loss}} \Big/ \text{Coefficient of performance of heat-creation}$$

Reduce leakiness

← Leakiness: 8 kWh/d/°C

New leakiness: 6 kWh/d/°C

Increase coefficient of performance - use Heat pumps



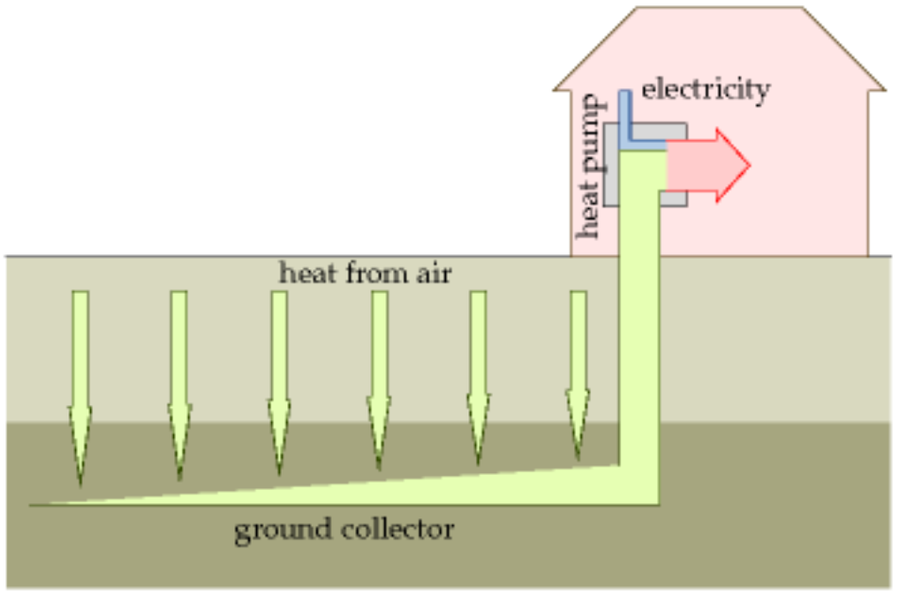
http://www.ecosystem-japan.com/

EcoCute water heater - CoP = 4.9!

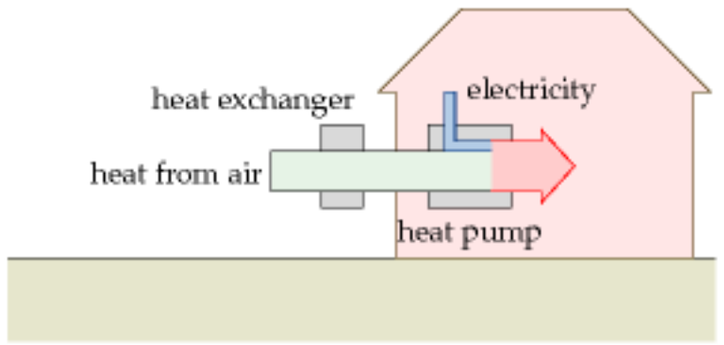
$$\text{Power required} = \boxed{\text{Heat loss}} \Big/ \begin{array}{c}\text{Coefficient of performance}\\ \text{of heat-creation}\end{array}$$

Heating without fossil fuels

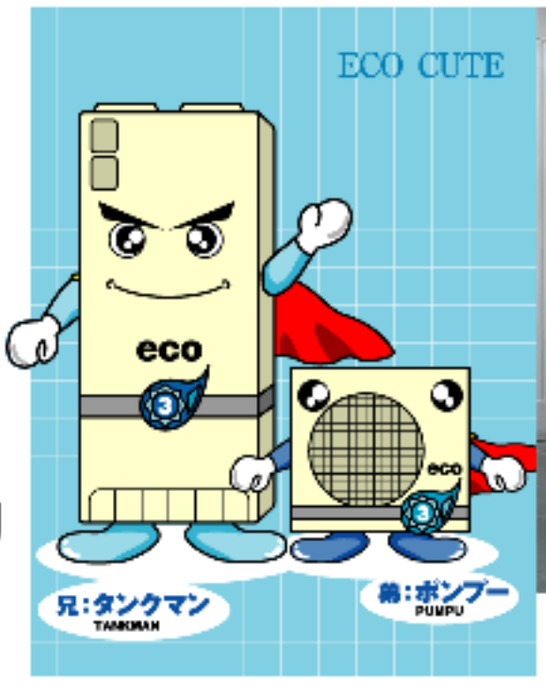
- Heat pumps, powered by electricity
  - Ground-source heat pumps



  - Air-source heat pumps

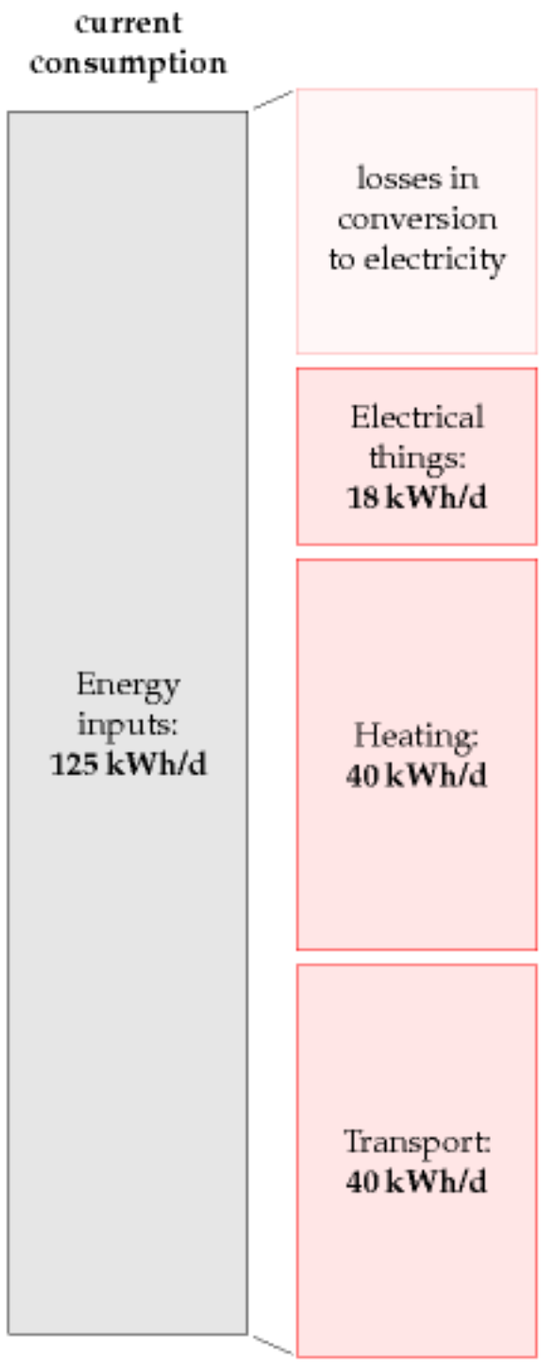


4 times more efficient than ordinary electric heating



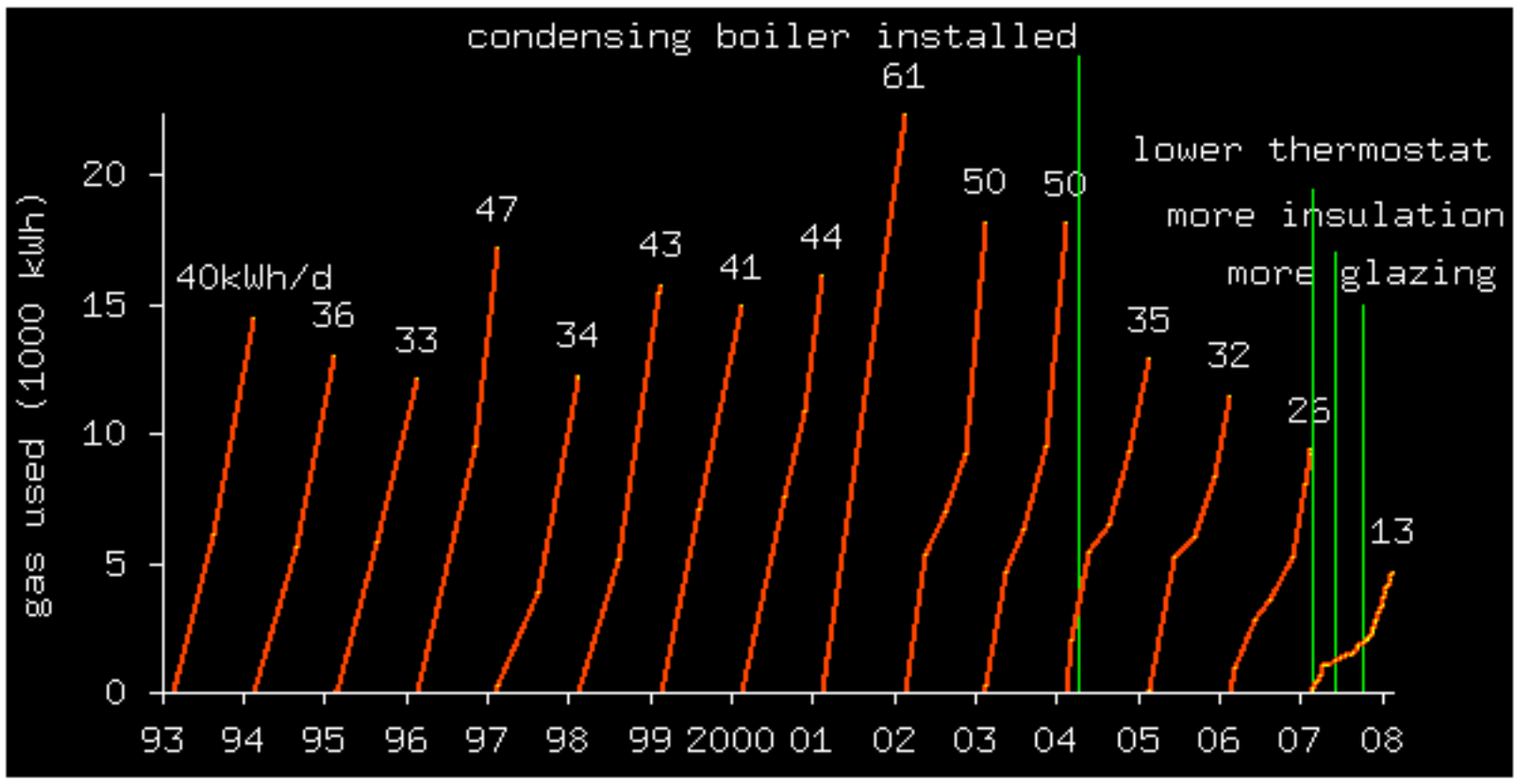
EFFICIENCY

- Cartoon Britain, 2008

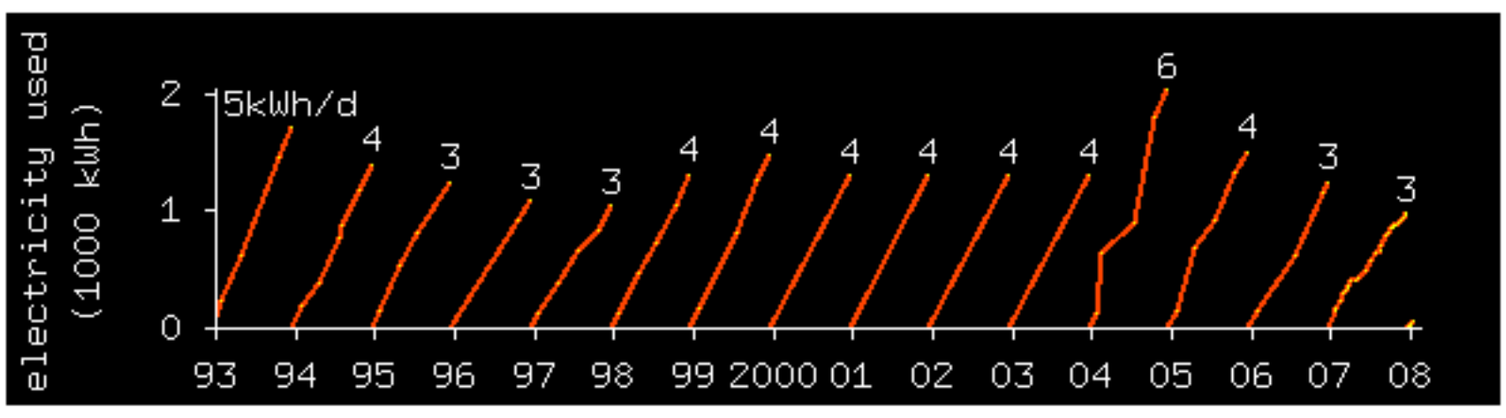


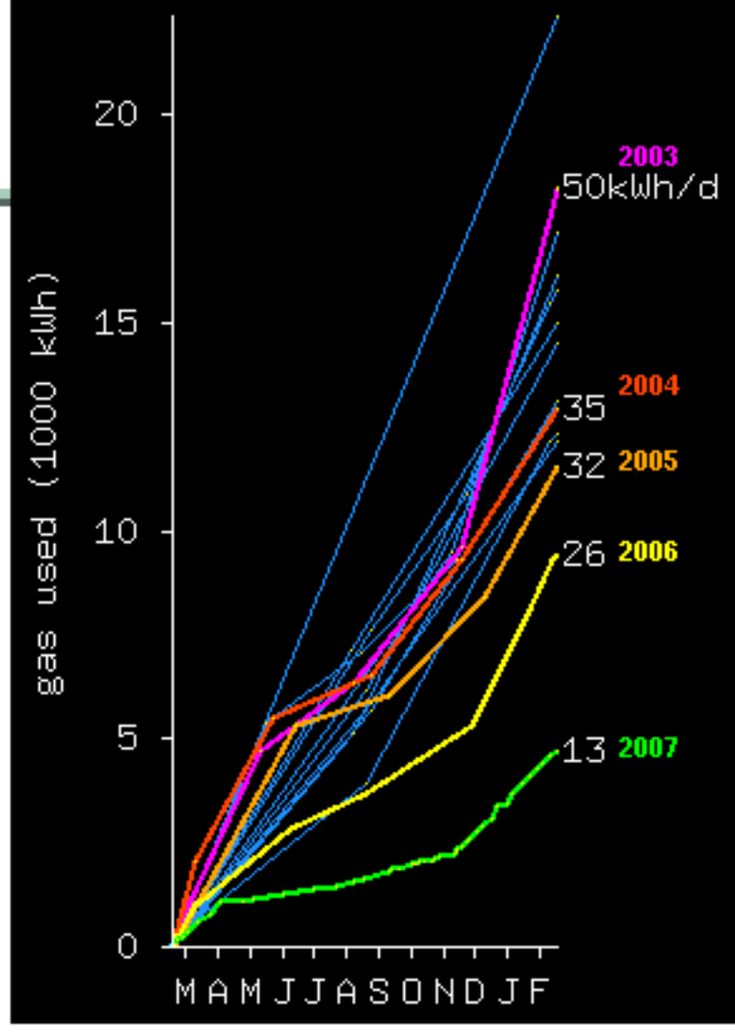
Read your meters!

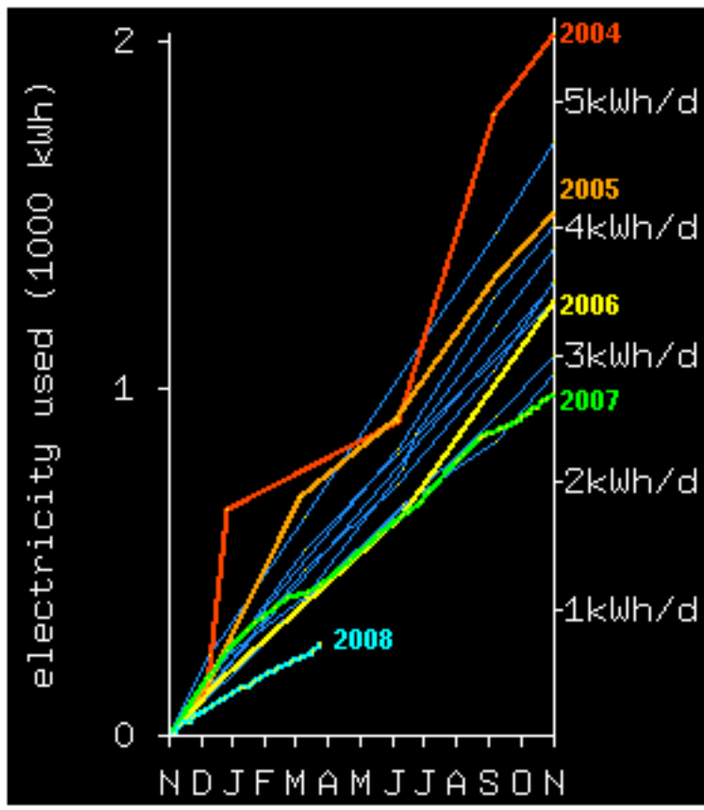
Gas



Electricity

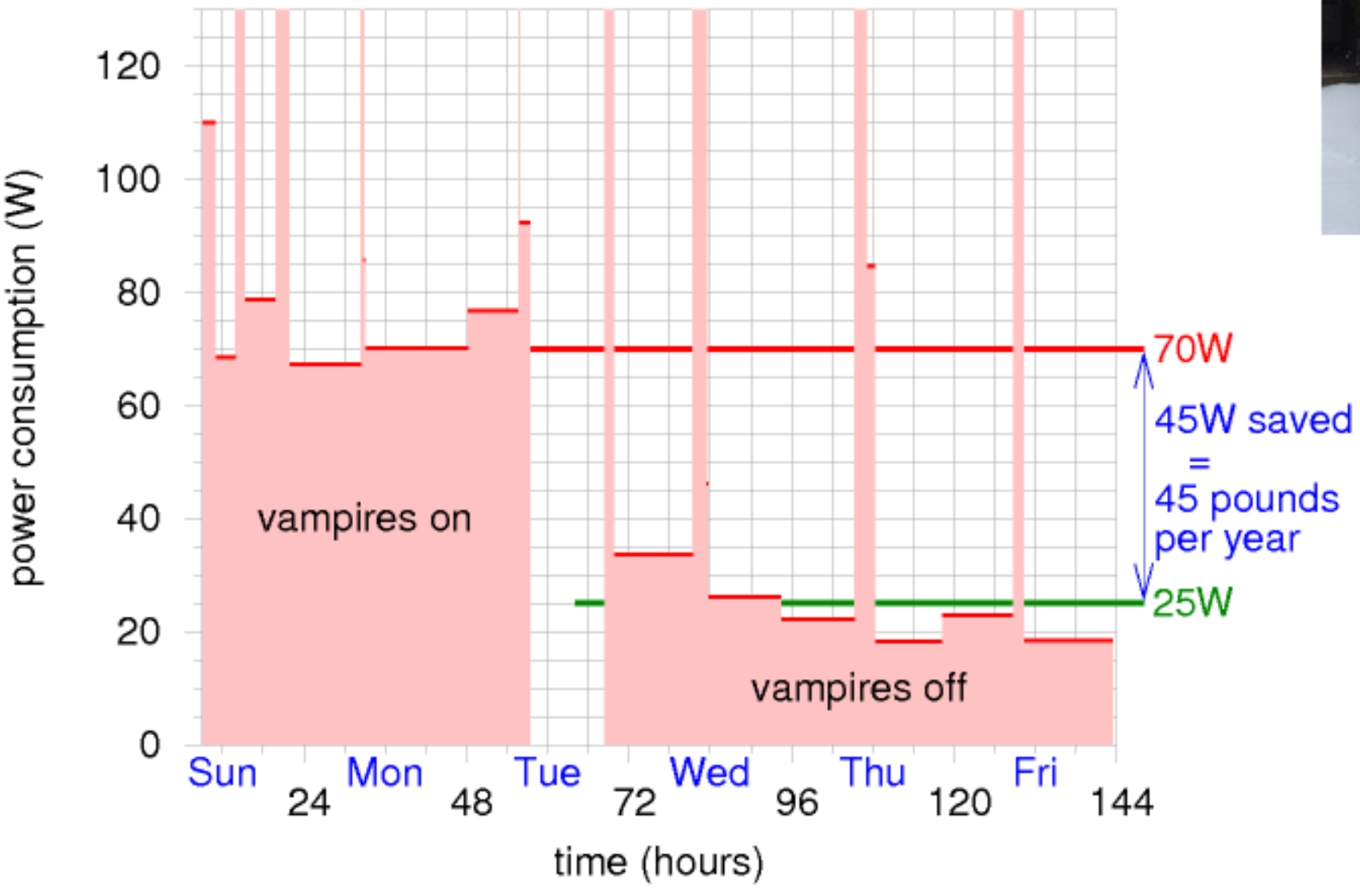






Efficiency in the offing

- Electricity



ReadYourMeter.org

Efficiency and technology

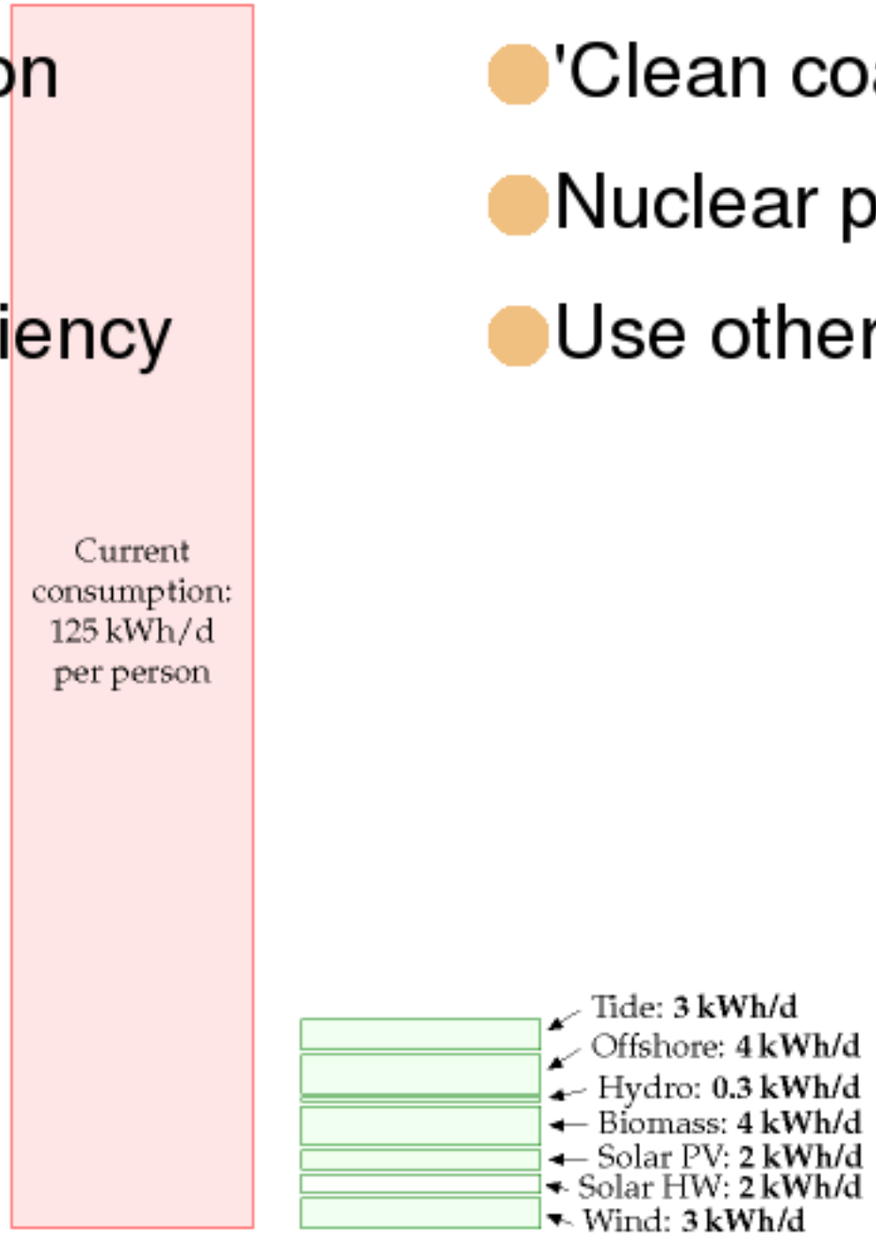
- Jevons' paradox

"as technological improvements increase the efficiency with which a resource is used, total consumption of that resource may increase, rather than decrease."

For example, from 1900 to 2000, passenger transportation in the USA became 5 times more energy-efficient; but nowadays, the average person travels 50 times further.

How to make an energy plan that adds up

- Demand-side
  - Reduce population
  - Change lifestyle
  - Technology, efficiency
- Supply-side
  - 'Clean coal'
  - Nuclear power
  - Use other countries' renewables



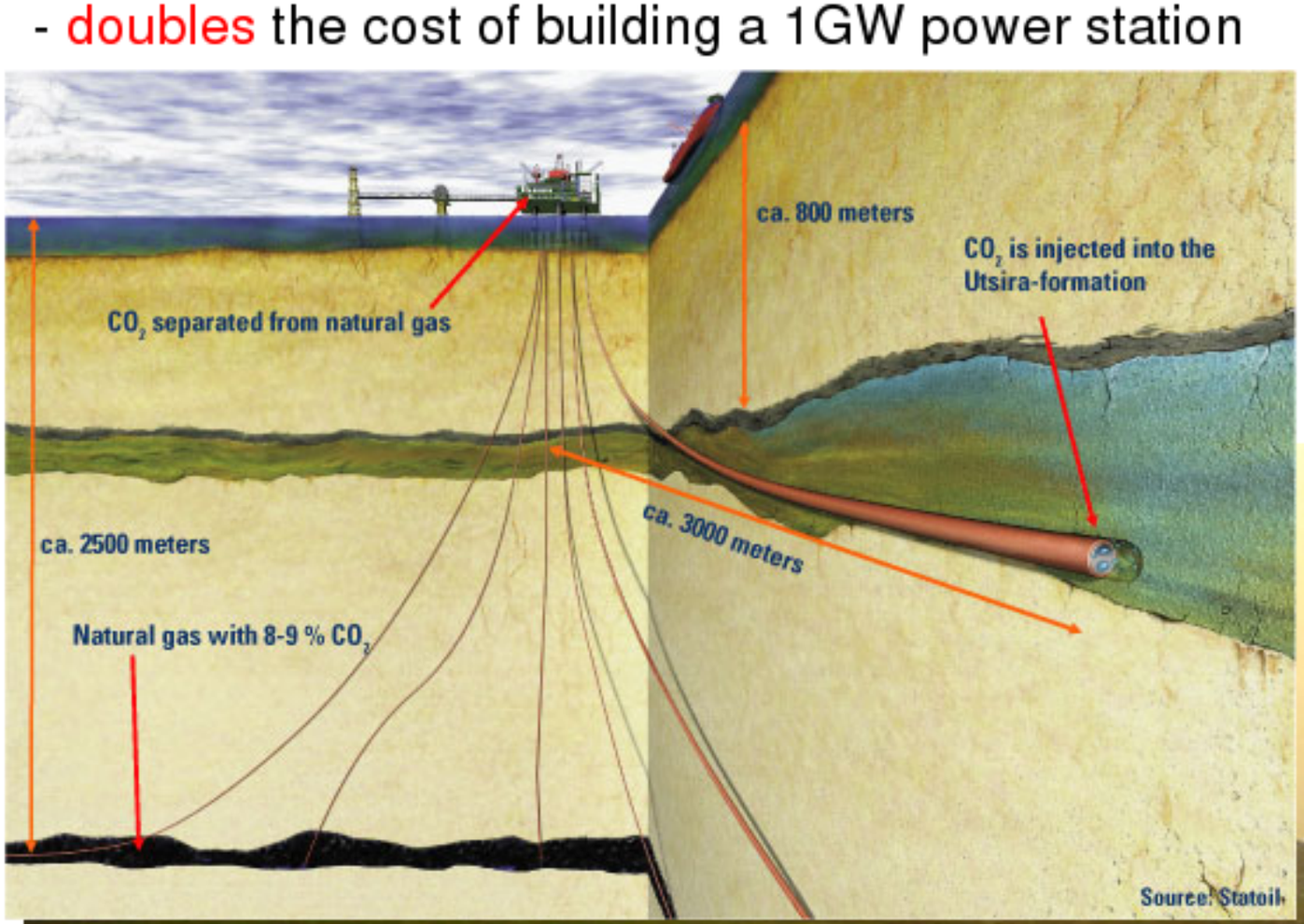
'Sustainable fossil fuels'

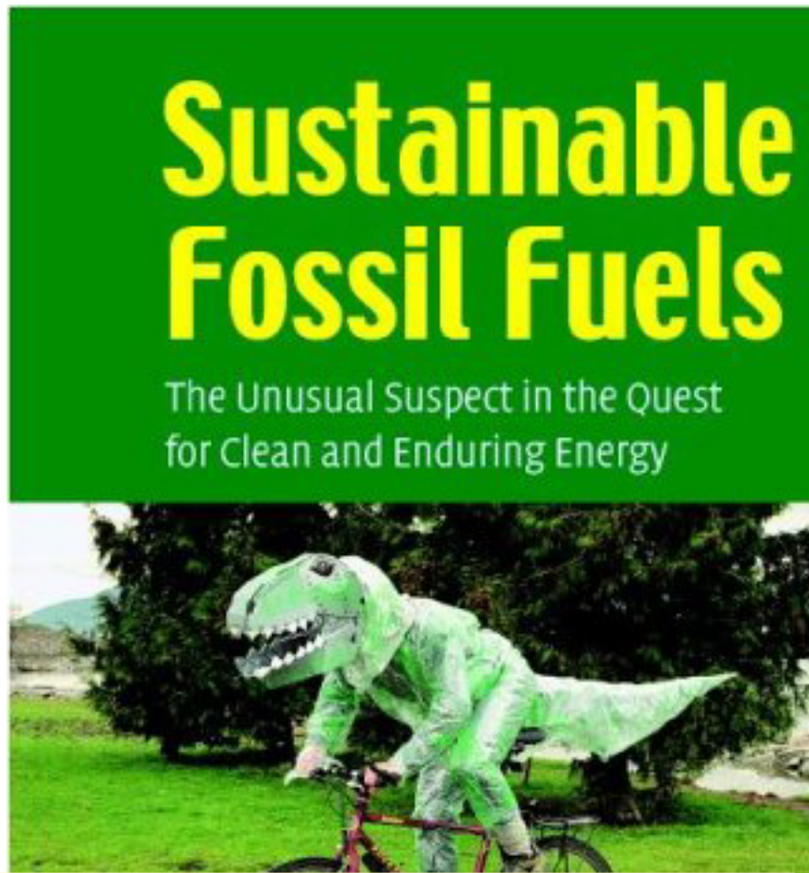
$$\frac{1600\ \text{Gt of coal}}{6\ \text{billion people}} \Big/ 1000\ \text{years} \times 8000\ \text{kWh per tonne} = 6\,\text{kWh per day per person}$$

Coal:
6 kWh/d

Carbon capture and storage

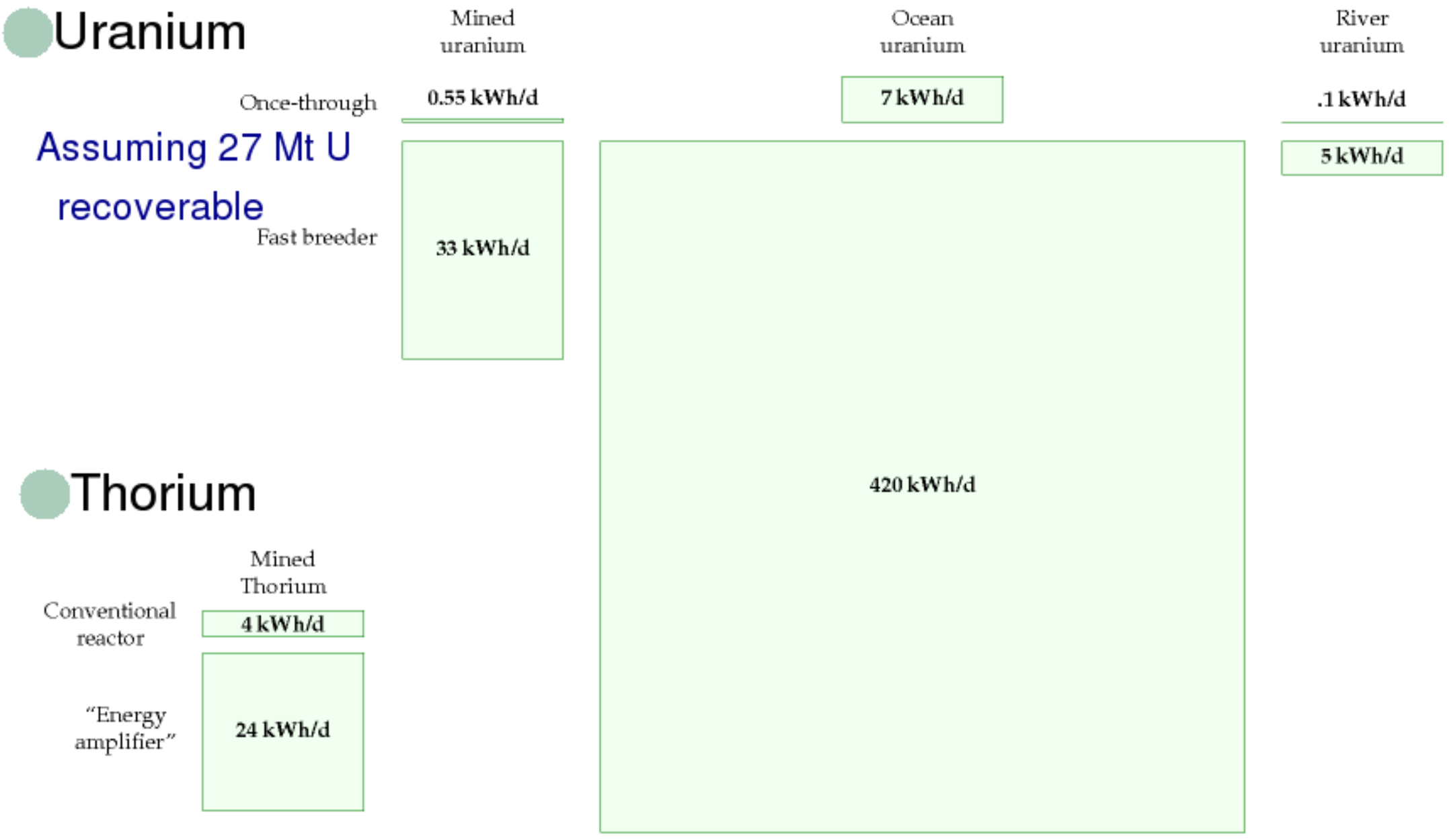
- requires 25% of the generated energy
- doubles the cost of building a 1GW power station





Nuclear Fission ('sustainable' = 1000 years)

Uranium



Assuming 27 Mt U recoverable

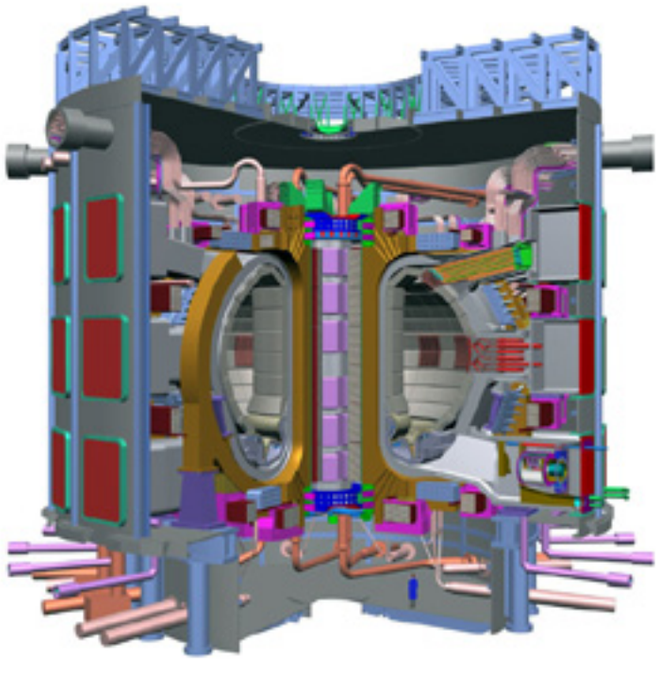
Thorium

Assuming 1.6 Mt Th recoverable

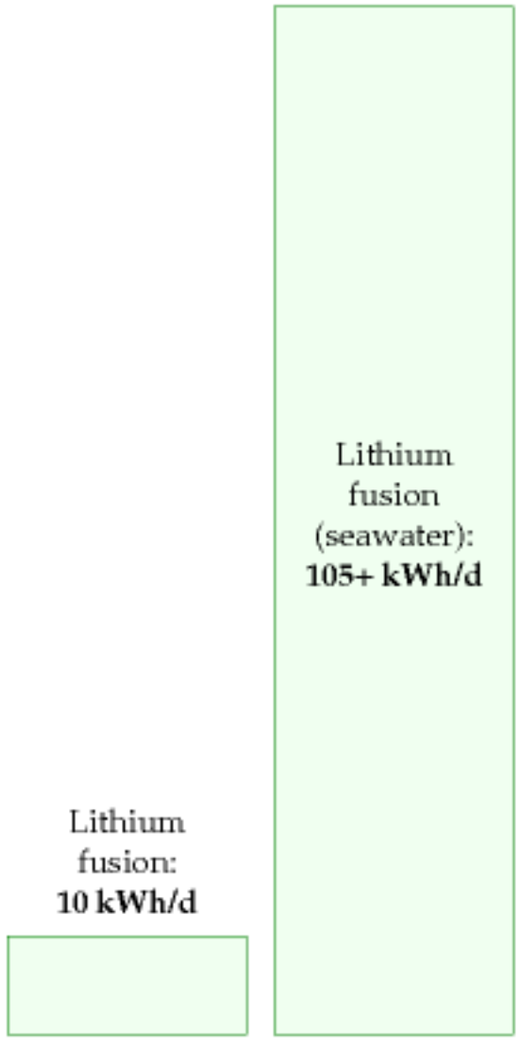
3f(summary) / 5f(CSP)

Nuclear Fusion

- Not a sure thing
  - a gamble



- DT reaction
  - requires Lithium and Deuterium
- DD reaction
  - requires Deuterium

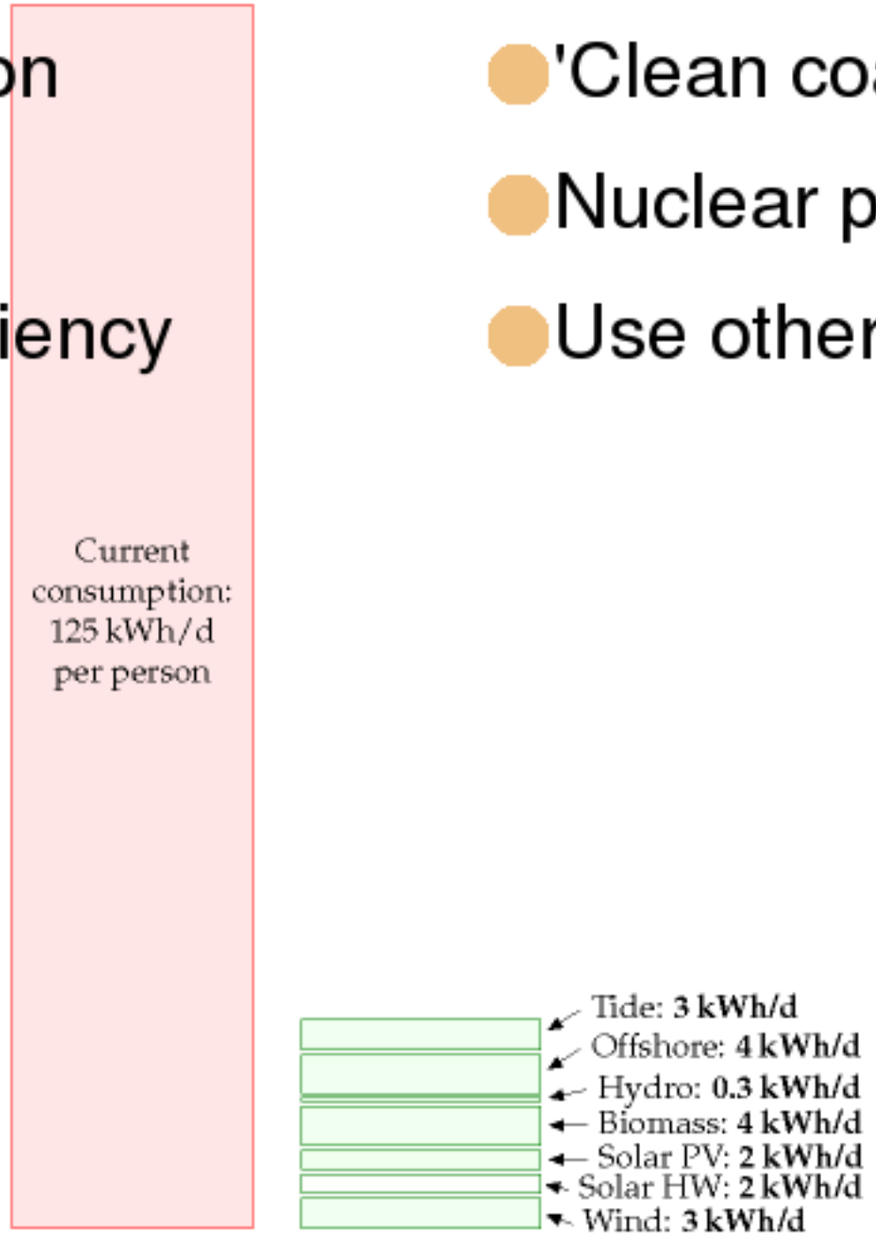


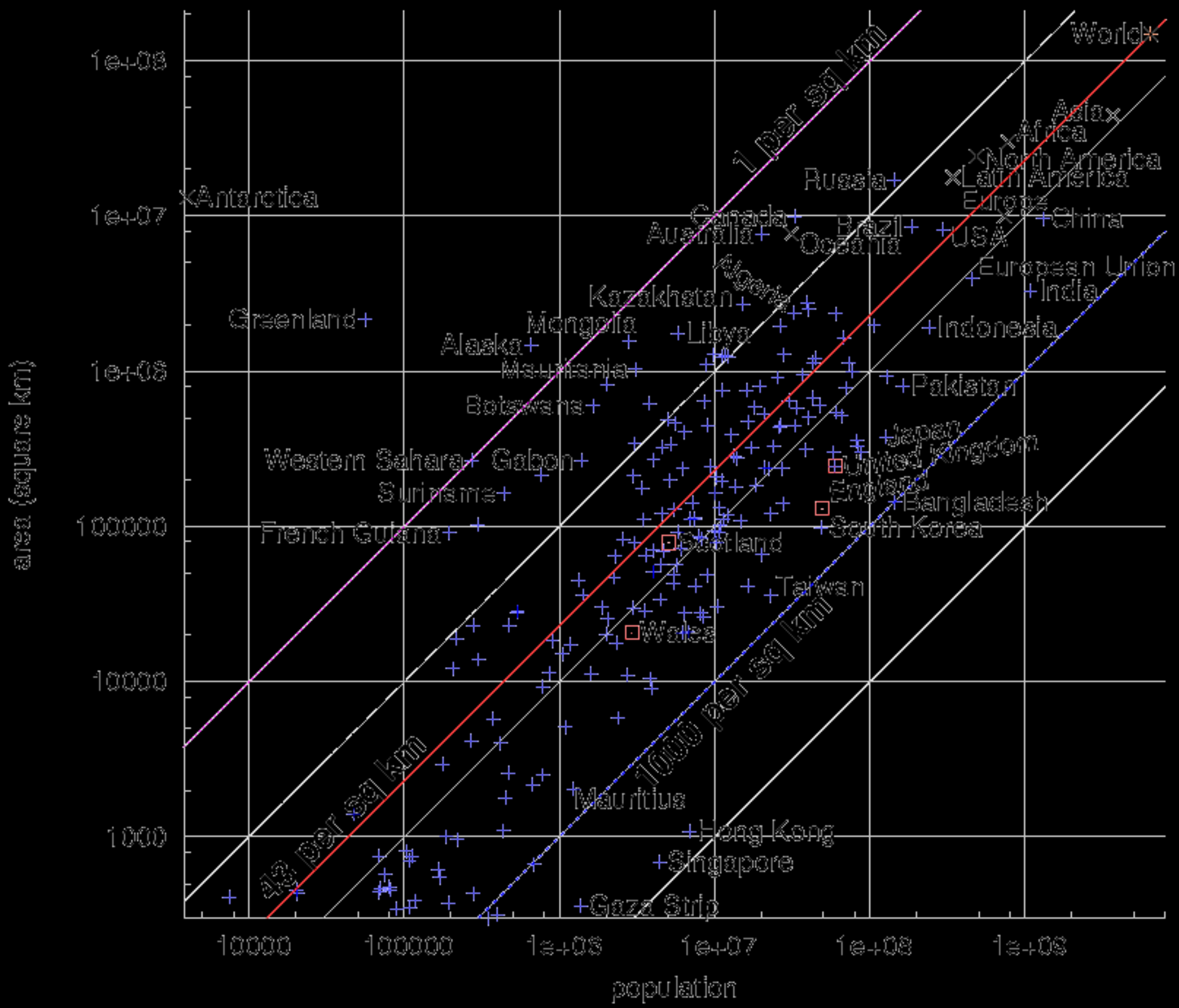
DD reaction

D lasts ~ 1 billion years

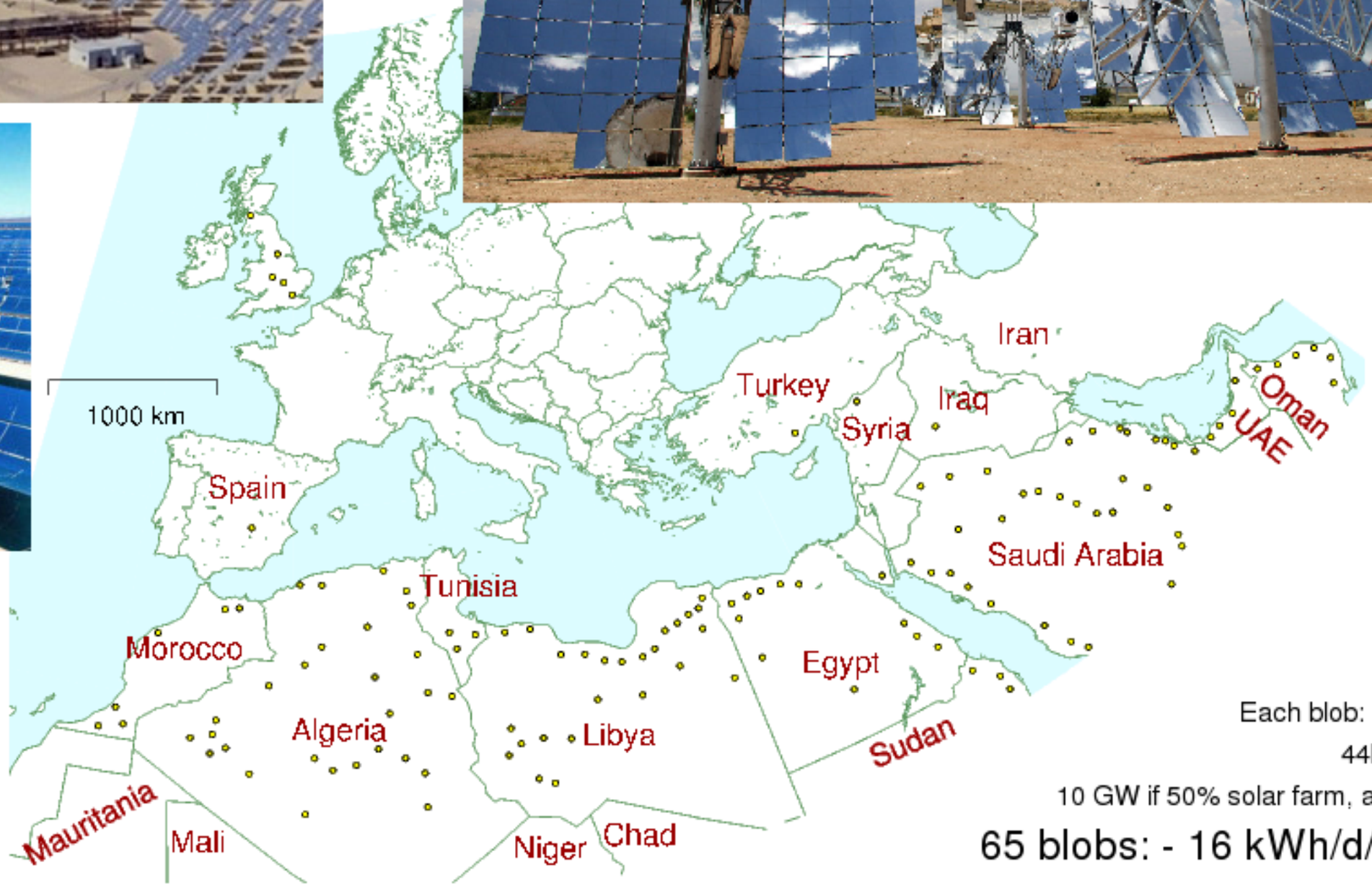
How to make an energy plan that adds up

- Demand-side
  - Reduce population
  - Change lifestyle
  - Technology, efficiency
- Supply-side
  - 'Clean coal'
  - Nuclear power
  - Use other countries' renewables



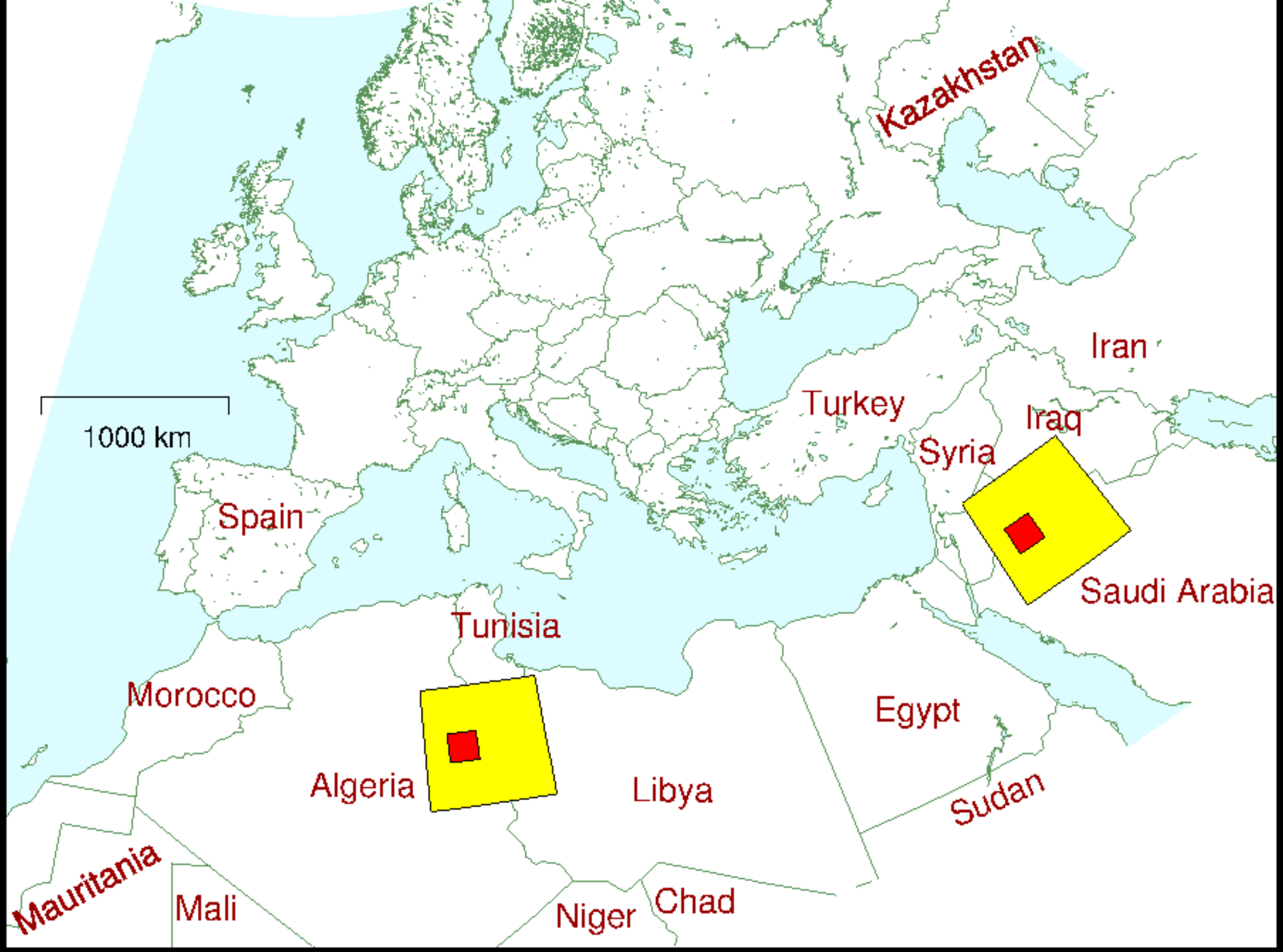

1e+08
1e+07
1e+06
100000
10000
1000
area (square km)
10000
100000
1e+06
1e+07
1e+08
1e+09
population
1 per sq km
43 per sq km
1000 per sq km
World
Asia
Africa
North America
Latin America
Europe
China
European Union
India
Indonesia
Pakistan
Bangladesh
South Korea
Japan
United Kingdom
England
Taiwan
Wales
Mauritius
Hong Kong
Singapore
Gaza Strip
Russia
Canada
Australia
Oceania
Brazil
USA
Kazakhstan
Greenland
Mongolia
Libya
Alaska
Western Sahara
Botswana
Gabon
Suriname
French Guiana
Scotland
Antarctica

International options



Each blob: 1500 sq km;
44km diameter;
10 GW if 50% solar farm, at 15 W/sq m.

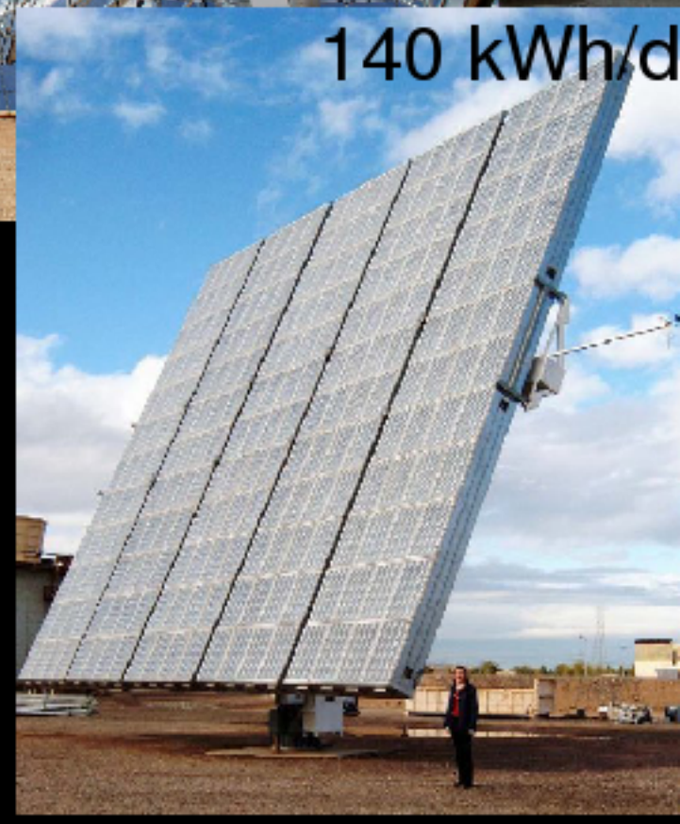
65 blobs: - 16 kWh/d/p x 1Gp



(assuming $15\,\mathrm{W/m^2}$)

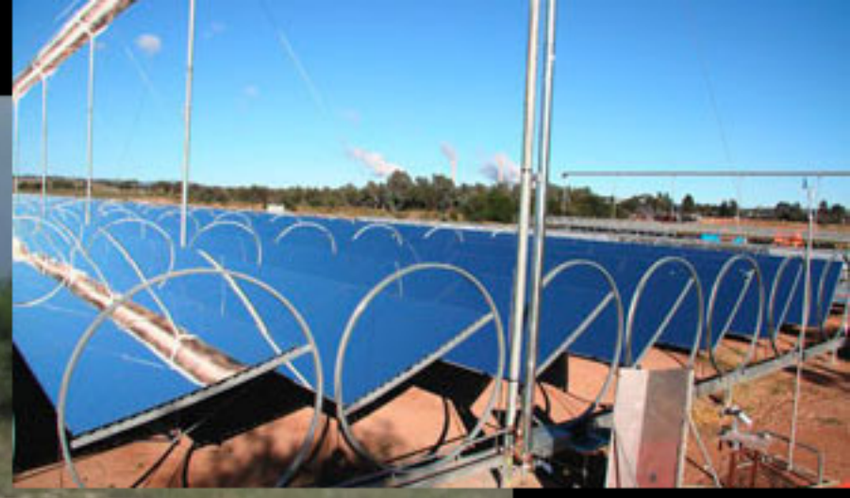
9f (a plan)


www.stirlingenergy.com


140 kWh/d

Spain
1000 km
Morocco
Tunisia
Algeria
Libya
Mauritania
Mali
Niger
Chad
65 b

www.stirlingenergy.com



Andasol, Spain

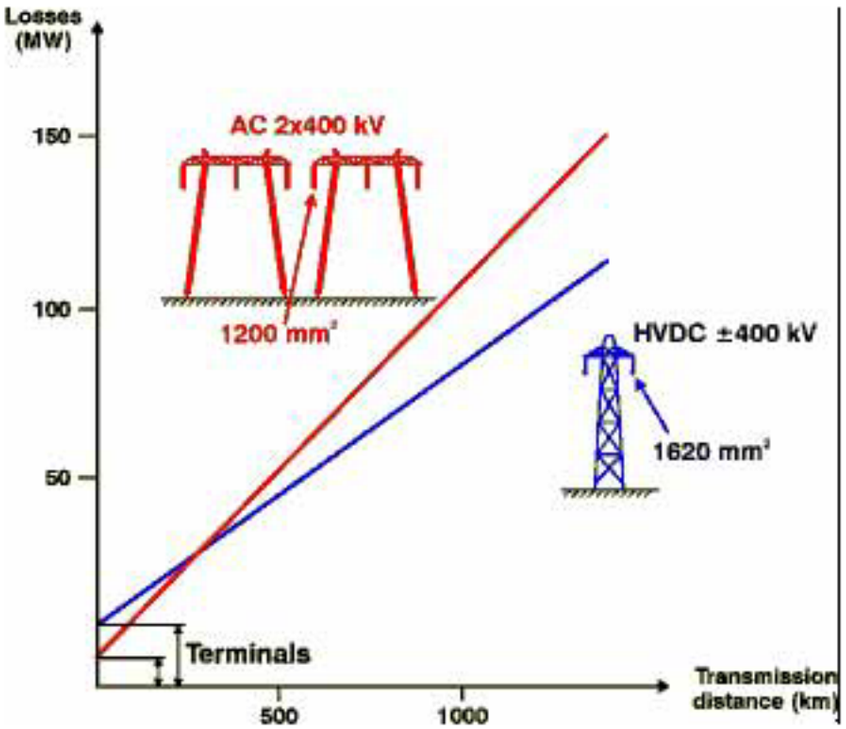
$10\ \mathrm{W/m^2}$

PS10, Solucar

$5\,\mathrm{W/m^2}$

Photo by afloresm

HVDC transmission



Photos and diagrams: ABB

2GW -->

3.1GW, 1360km

1.9GW, 1420km

Mozambique - South Africa

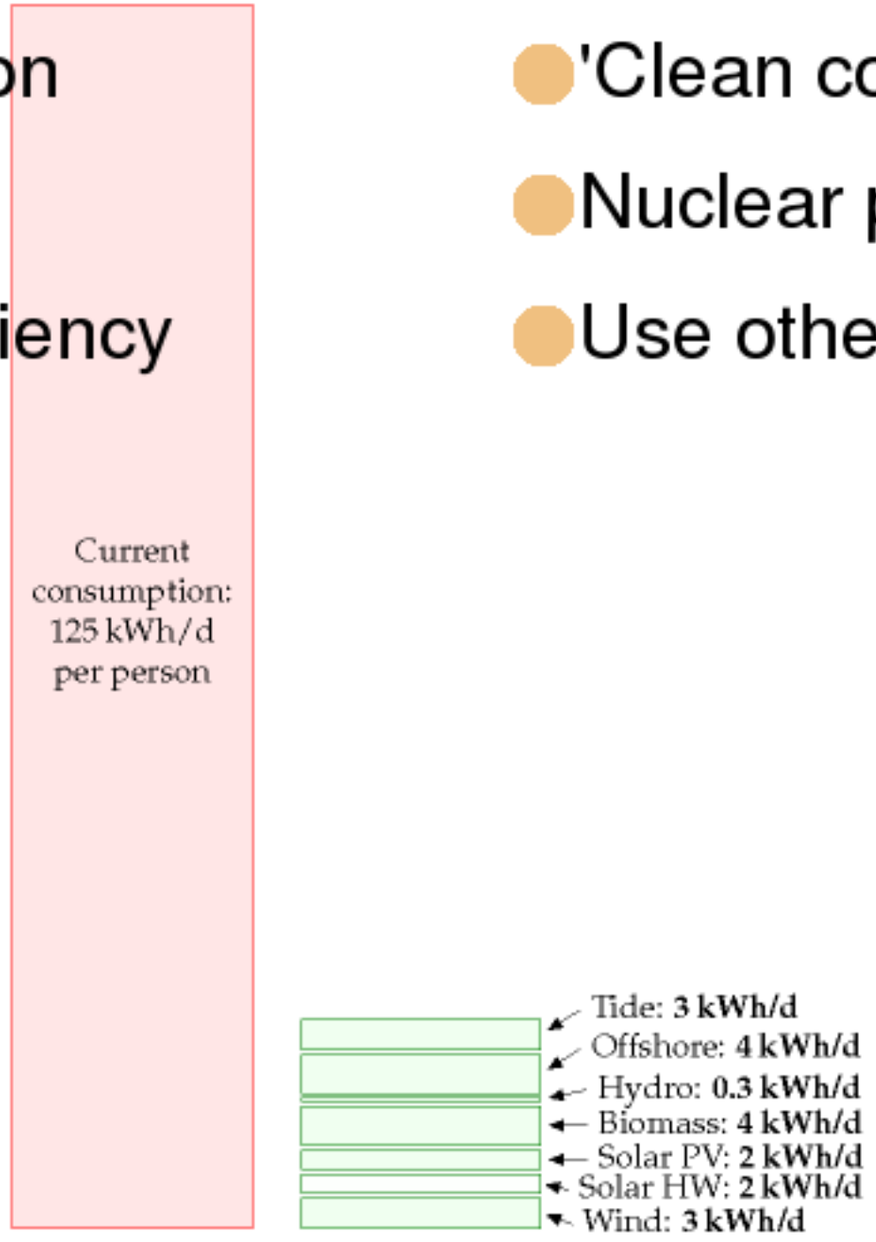
0.7GW, 580km

Photos: ABB

and - Estonia:
pair of cables
nsmit 350 MW

How to make an energy plan that adds up

- Demand-side
  - Reduce population
  - Change lifestyle
  - Technology, efficiency
- Supply-side
  - 'Clean coal'
  - Nuclear power
  - Use other countries' renewables

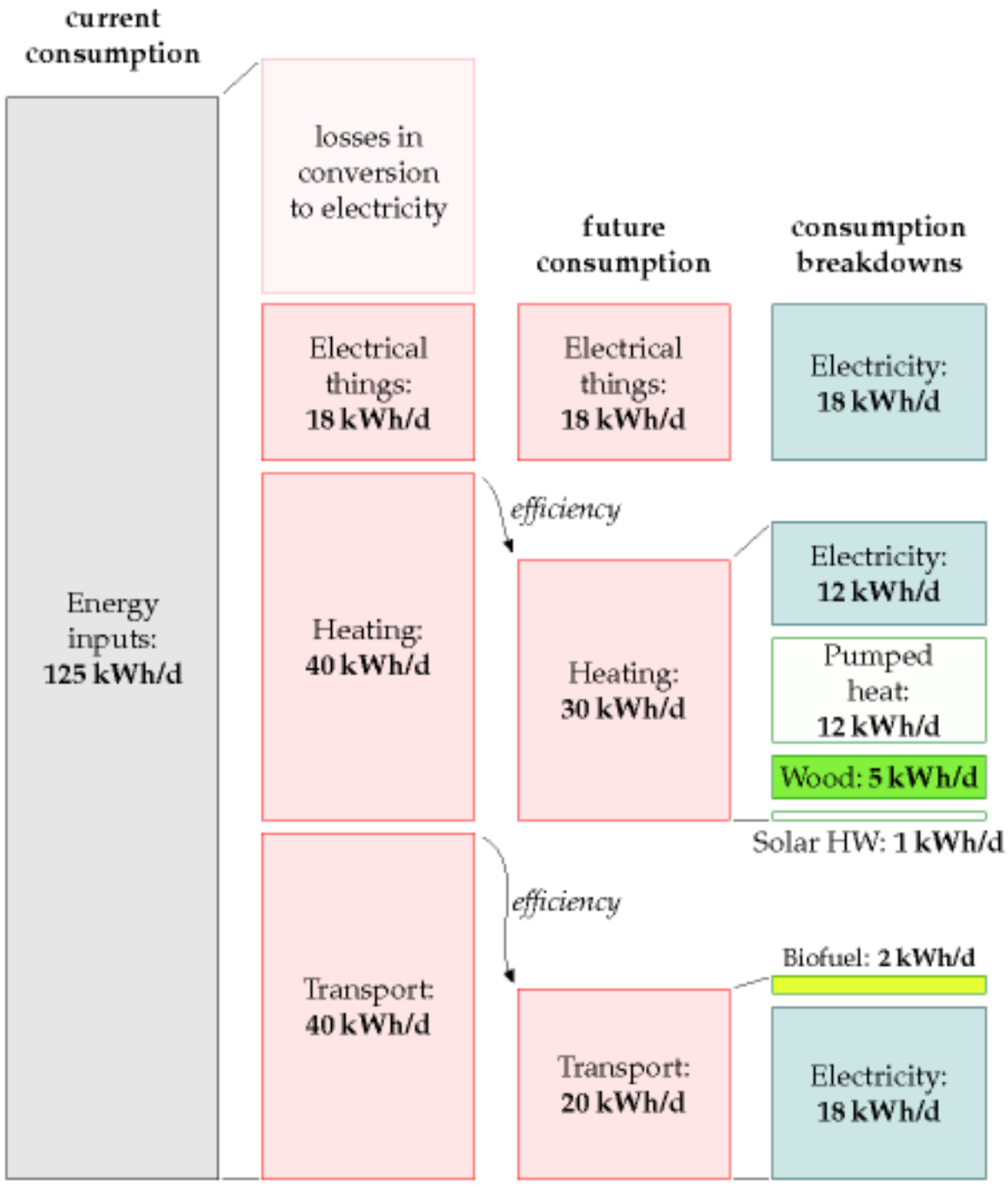


How to get the UK off fossil fuels

- Transport, Heating, Electricity
  - Electrify all transport
  - Insulate all buildings; read all meters
  - Electrify all building-heating
    - air-source or ground-source heat pumps
    - (not combined heat and power)

- Our renewables
- Nuclear? (stop-gap?)
- 'Clean coal'? (stop-gap)
- Other people's renewables

One cartoon plan



Key ideas

Insulation

Heat pumps

25% of UK

forests, willow, miscanthus

1 sq m per person HW

12% of UK for biofuels

Electric vehicles

50 kWh/d is 125 GW

tidal stream farms

100 sq km wind farms

Loch Shin

Loch Maree

Loch Ness

Foyers

Loch Morar

Loch Shiel

Loch Ericht

Blackwater

Loch Rannoch

Loch Tay

Cruachan

Loch Awe

Loch Katrine

Loch Sloy

Loch Leven

Biofuels

65km wave farm

100 km

Wood/Miscanthus

Solar in deserts: **16 kWh/d**

Clean coal: **3**

Nuclear: **16 kWh/d**

Tide: **3.7**

Wave: **0.3**

Hydro: **0.2**

Waste: **1.1**

Pumped heat: **12 kWh/d**

Wood: **5 kWh/d**

Solar HW: **1**

Biofuels: **2**

PV: **2**

Wind: **8**

tidal stream farms

100 sq km wind farms

Biofuels

Hartlepool

Wood/Miscanthus

Sellafield

Heysham

100 km

Drax

Ferrybridge

Wylfa

tidal lagoons

Dinorwig

Ffestiniog

Trawsfynydd

Sizewell

Bradwell

Berkeley

Oldbury

Didcot

65km wave farm

Kingsnorth

Hinkley Point

Dungeness

HVDC power lines

Photovoltaics

Solar power in deserts

This plan's mix

Solar in deserts: **16 kWh/d**

Clean coal: **3**

Nuclear: **16 kWh/d**

Tide: **3.7**

Wave: **0.3**

Hydro: **0.2**

Waste: **1.1**

Pumped heat: **12 kWh/d**

Wood: **5 kWh/d**

Solar HW: **1**

Biofuels: **2**

PV: **2**

Wind: **8**

Four Londons' worth

Use for cofiring biomass with CCS

40GW - four-fold increase

25% of UK - forests, willow, miscanthus

1 sq m per person HW

12% of UK for biofuels

Half of all roofs

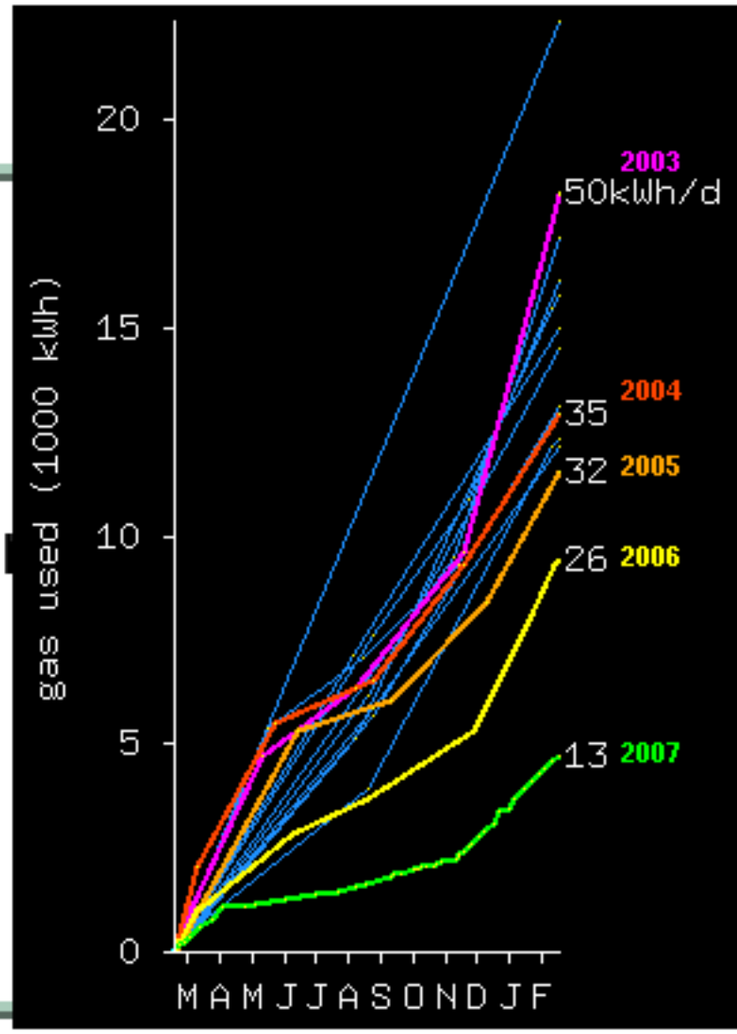
33-fold increase in wind capacity

[Jet flights: 5kWh/d/p, while oil lasts]

Jack-up barges cost 60M

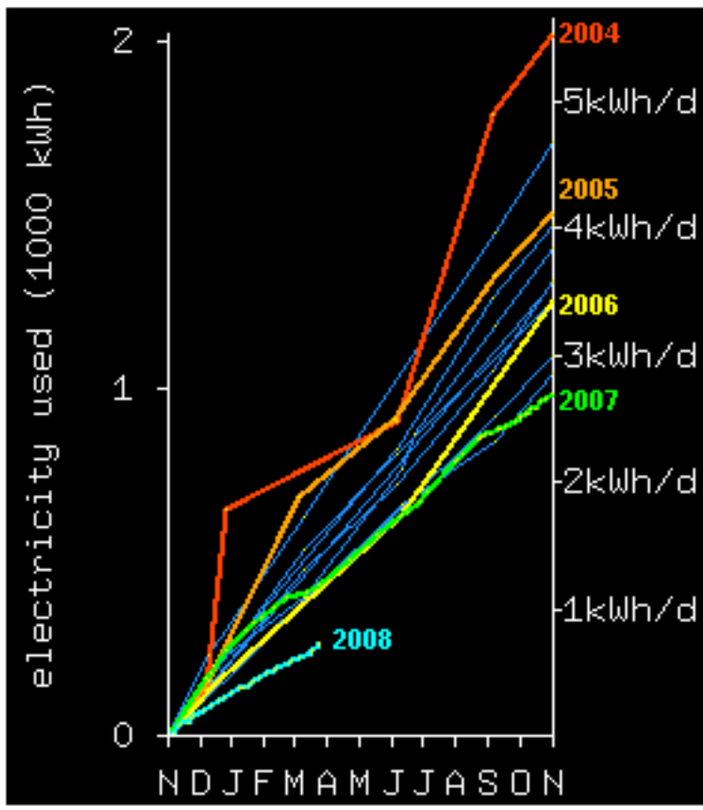
What society must do

- Choose a plan that adds up
- Carbon price
- No coal or gas power stations without carbon captu



What individuals can do

- Read meters
- Say yes to plans that add up



Getting off fossil fuels is not easy, but it is possible

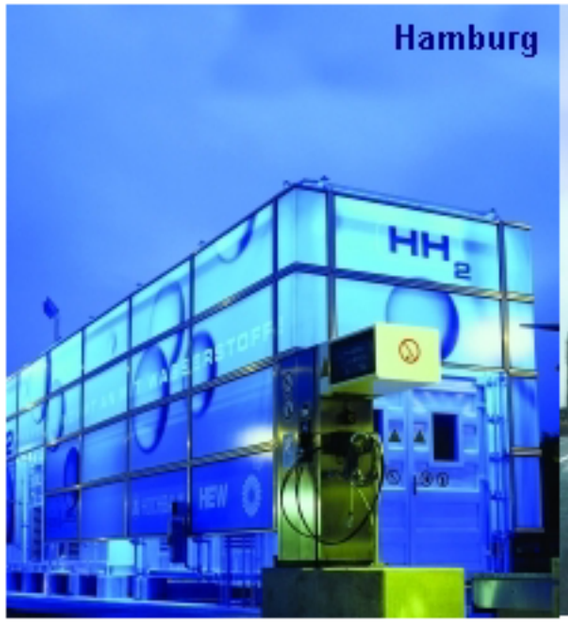
- A Plan that adds up must have some or all of:
  - country-sized renewable facilities
  - renewables from other people's countries
  - lots of nuclear power
- And efficiency too of course

'Okay - it's agreed; we announce - "to do nothing is not an option!" then we wait and see how things pan out...'

Lowe, Private Eye

Hydrogen

SUSTAINABLE
TRANSPORT
ENERGY



Clean Urban Transport for Europe

hydrogen made from fossil fuels:

overall primary energy consumption by the hydrogen buses was between 80% and 200% greater than that of the baseline diesel bus.

GHG emissions were between 40% and 140% greater.

BMW Hydrogen 7

254 kWh per 100 km

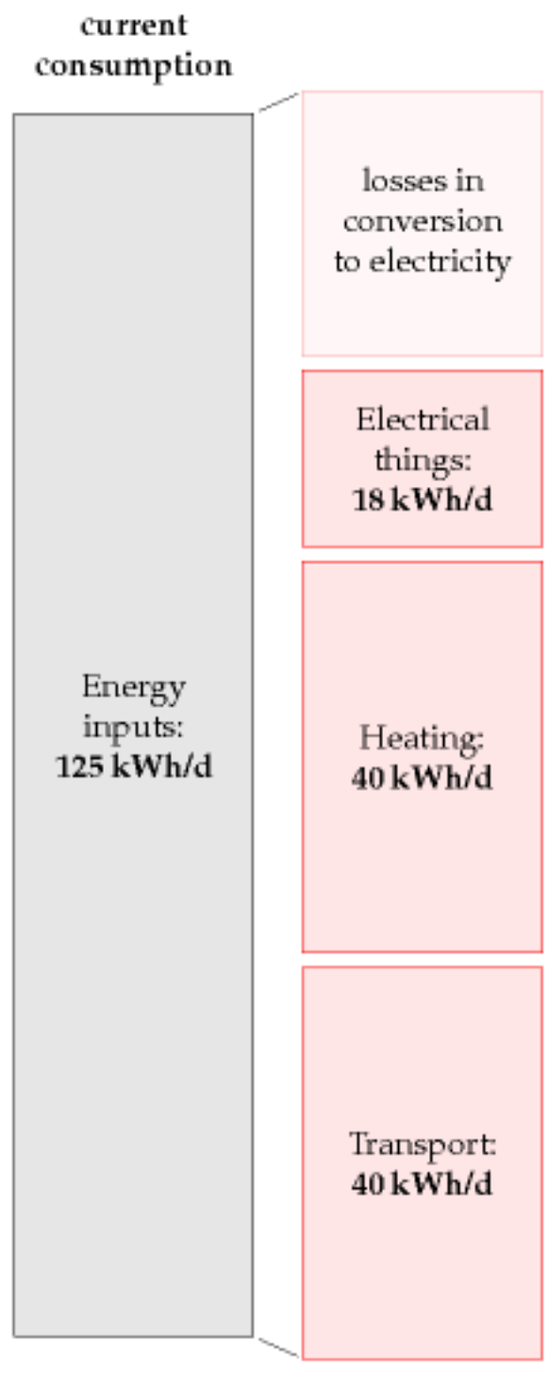
Honda's fuel-cell car (FCX Clarity)

69 kWh per 100 km

Efficiency & technology - for Cartoon-Britain

The current situation in Cartoon-Britain

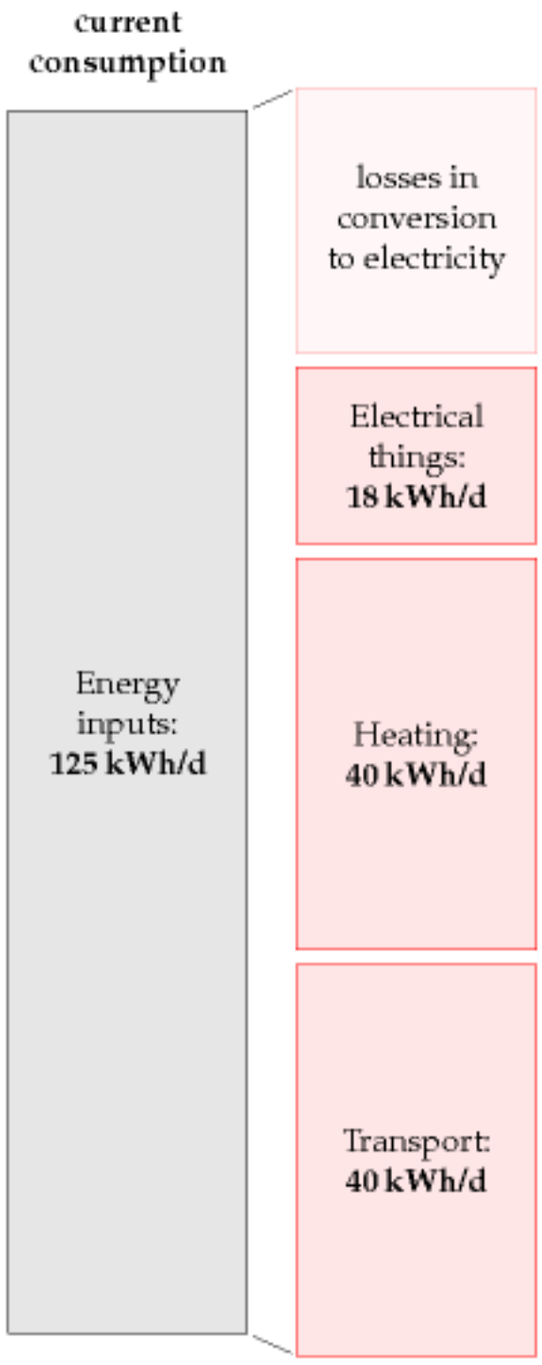
(ignoring embodied energy in imported stuff)



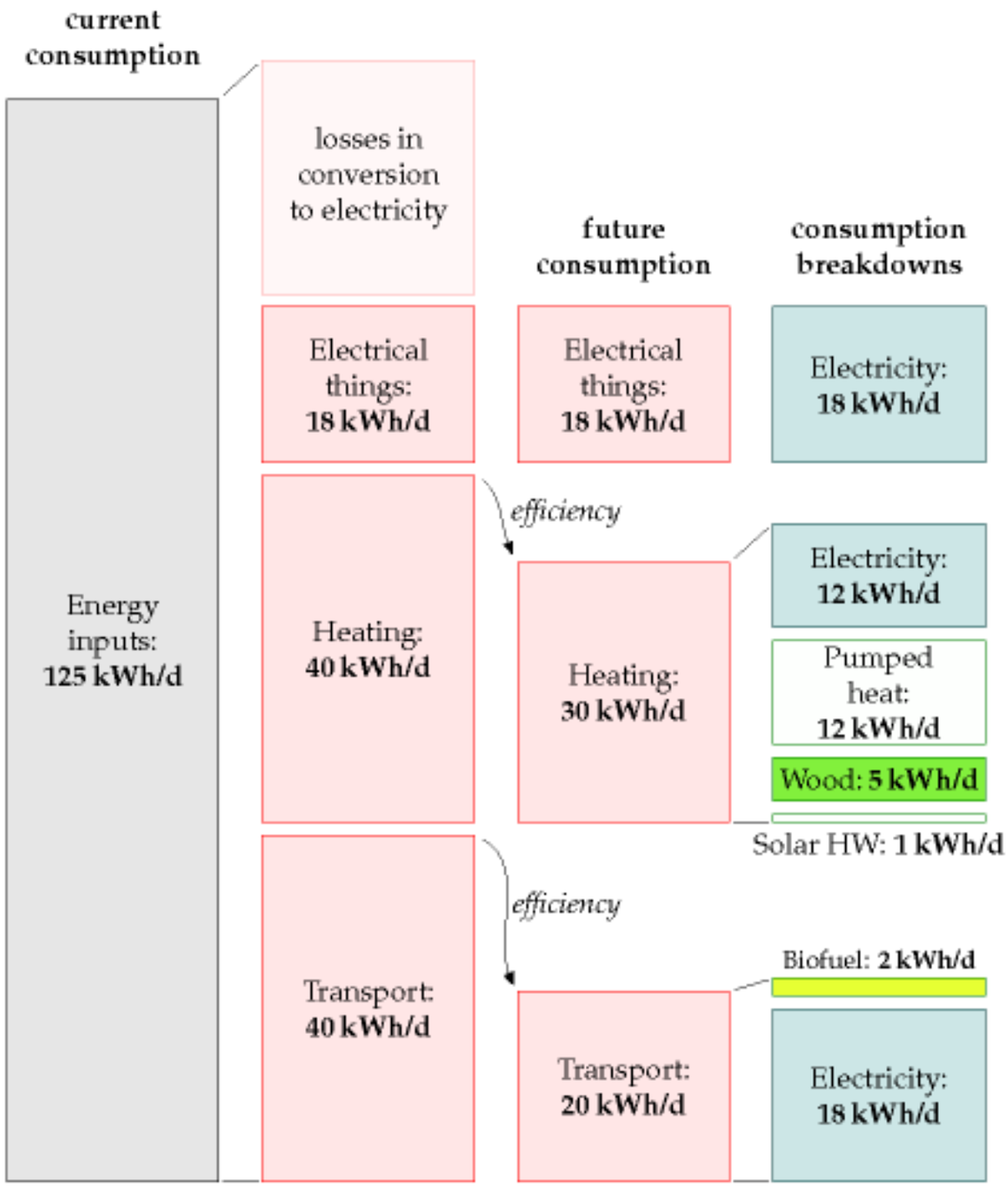
Efficiency

- Improving transport efficiency
- Improving heating efficiency

Efficiency & technology - for Cartoon-Britain



Five plans for Cartoon-Britain



Key ideas

Insulation

Heat pumps

25% of UK

forests, willow, miscanthus

1 sq m per person HW

12% of UK for biofuels

Electric vehicles

50 kWh/d is 125 GW

Plan D: 'Diversity'

40GW; triple coal imports

Clean coal: **16 kWh/d**

Nuclear: **16 kWh/d**

Tide: **3.7**

Wave: **2**

Hydro: **0.2**

Waste: **1.1**

Pumped heat: **12 kWh/d**

Wood: **5 kWh/d**

Solar HW: **1**

Biofuels: **2**

PV: **3 kWh/d**

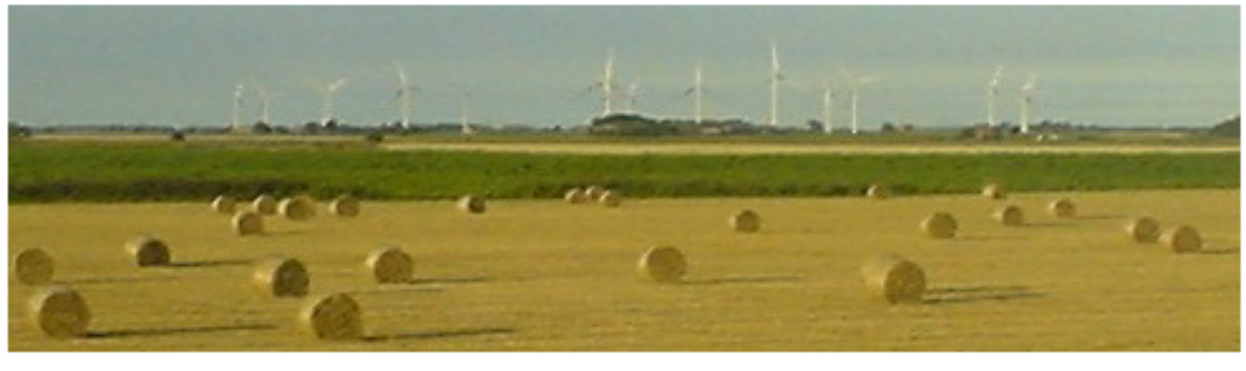
Wind: **8 kWh/d**

40GW - four-fold increase

7500 pelamis, 500km of coastline

all municipal waste incinerated, and equal agri. waste

7 sq m / p

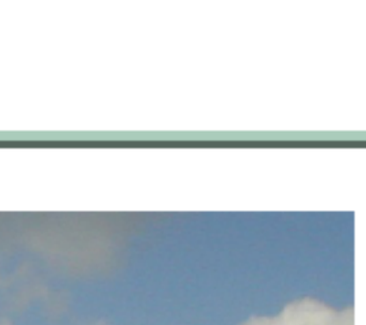


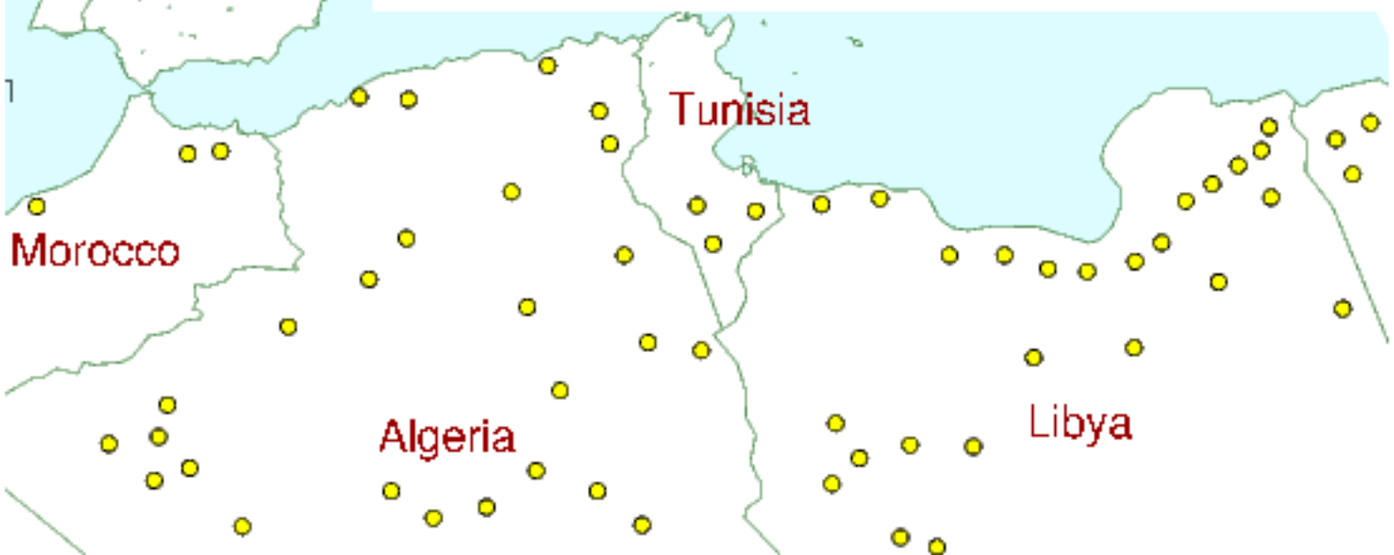
almost all the world's windmills ('60GW')

on 2% of country and equal area offshore

Plan N: 'NIMBY'

40GW; triple coal imports





Solar in deserts: **20 kWh/d**

Clean coal: **16 kWh/d**

Nuclear: **10 kWh/d**

Tide: **1 kWh/d**

Hydro: **0.2 kWh/d**

Waste: **1.1 kWh/d**

Pumped heat: **12 kWh/d**

Wood: **5 kWh/d**

Solar HW: **1 kWh/d**

Biofuels: **2 kWh/d**

Wind: **2 kWh/d**

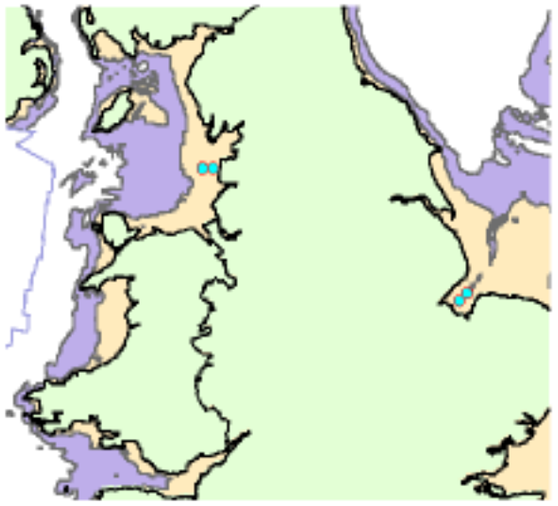
upgrade all current sites

all municipal waste incinerated, and equal agri. waste

8-fold increase in wind ('15GW')

Plan L: 'Libdem'

40GW; triple coal imports



Solar in deserts: **16 kWh/d**

Clean coal: **16 kWh/d**

Tide: **3.7**

Wave: **2**

Hydro: **0.2**

Waste: **1.1**

Pumped heat: **12 kWh/d**

Wood: **5 kWh/d**

Solar HW: **1**

Biofuels: **2**

PV: **3**

Wind: **8**

No nuclear

7500 pelamis, 500km of coastline

all municipal waste incinerated, and equal agri. waste

7 sq m / p

almost all the world's windmills ('60GW')

on 2% of country and equal area offshore

Plan G: 'Green'

No coal

7 sq m / p

Solar in deserts: 7

Tide: 3.7

Wave: 3

Hydro: 0.2

Waste: 1.1

Pumped heat: 12 kWh/d

Wood: 5 kWh/d

Solar HW: 1

Biofuels: 2

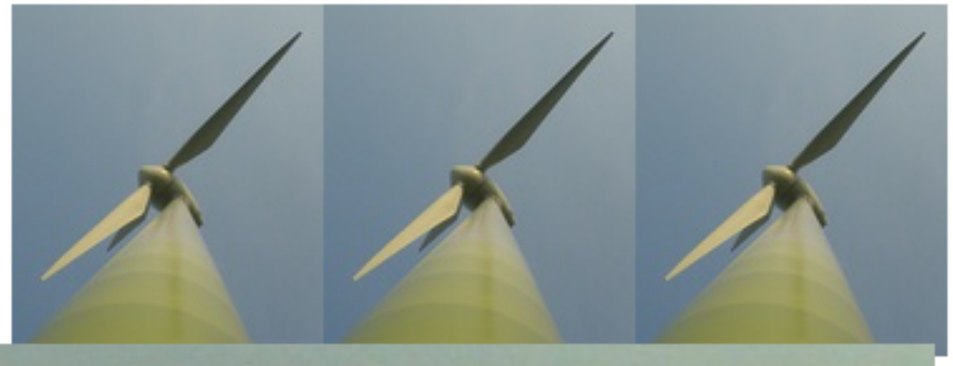
PV: 3

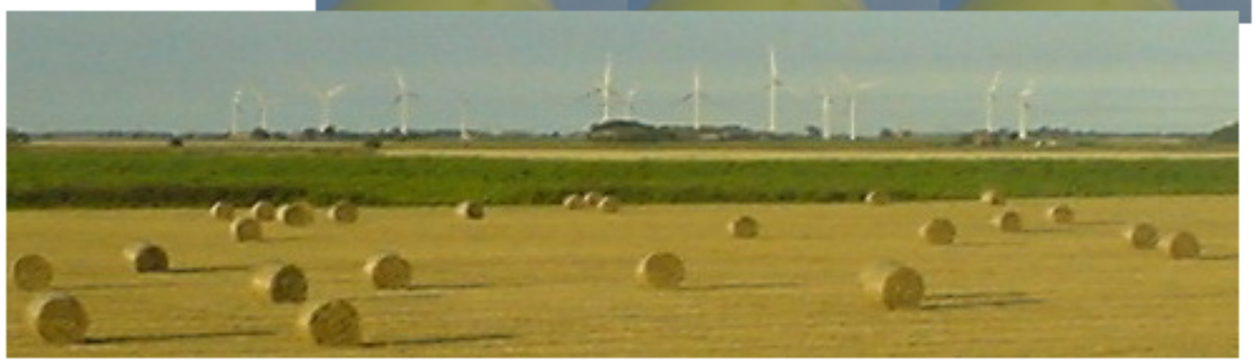
Wind: 32

No nuclear

11,000 pelamis, 750km of coastline

all municipal waste incinerated, and equal agri. waste





3 x all the world's windmills ('240GW') on 8% of country & equal area offshore

Plan E: 'Economist'

no coal - CCS more expensive than nuclear

110GW - twice France's nuclear

Tidal lagoons (providing storage too)

Nuclear: **44 kWh/d**

Tide: **0.7**

Hydro: **0.2**

Waste: **1.1**

Pumped heat: **12 kWh/d**

Wood: **5 kWh/d**

Solar HW: **1**

Biofuels: **2**

Wind: **4**

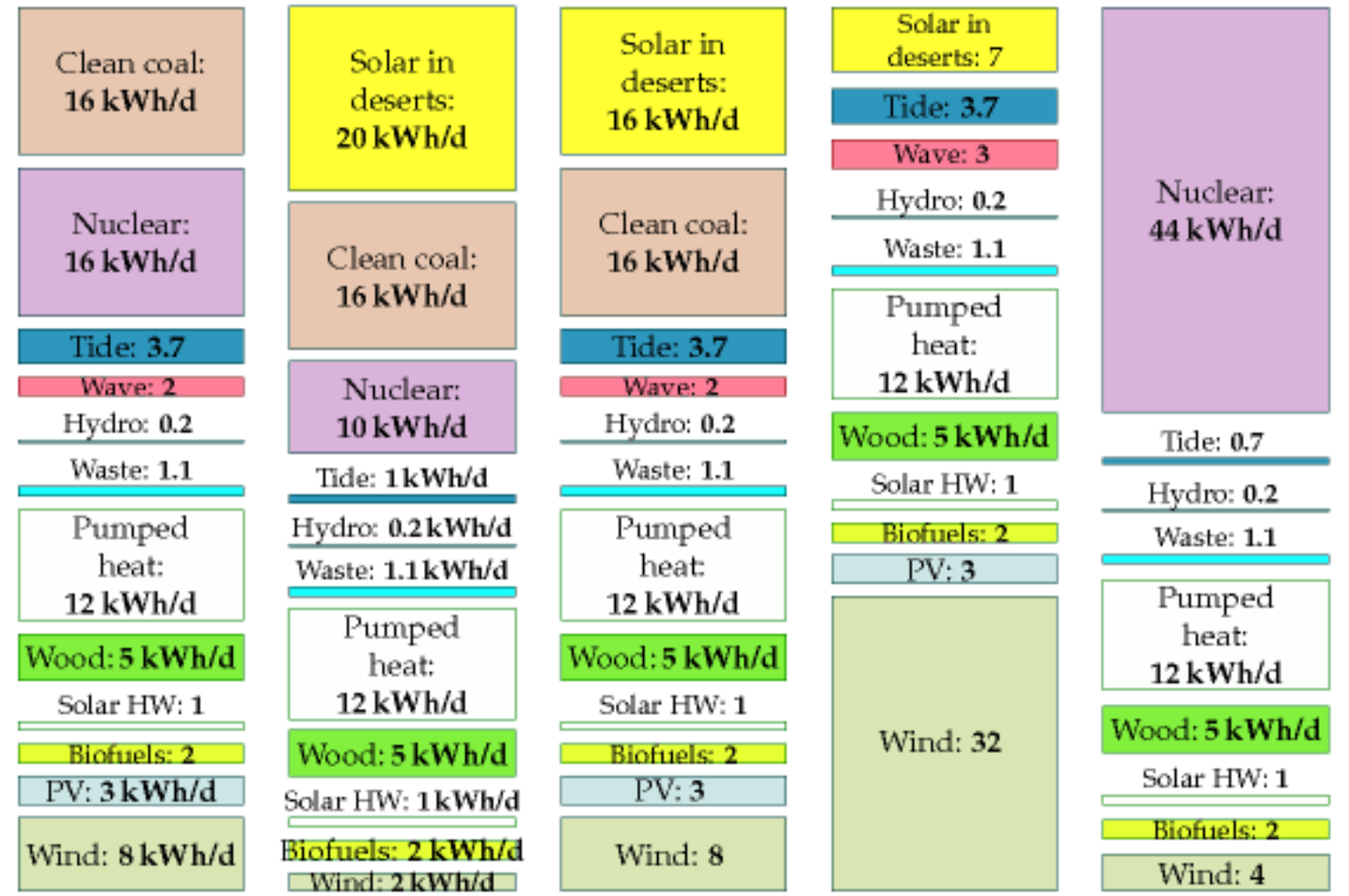
all municipal waste incinerated, and equal agri. waste

half the world's windmills ('30GW') on 1% of country and equal area offshore

10-fold increase in uranium

15-fold increase in wind

Five plans for Cartoon-Britain



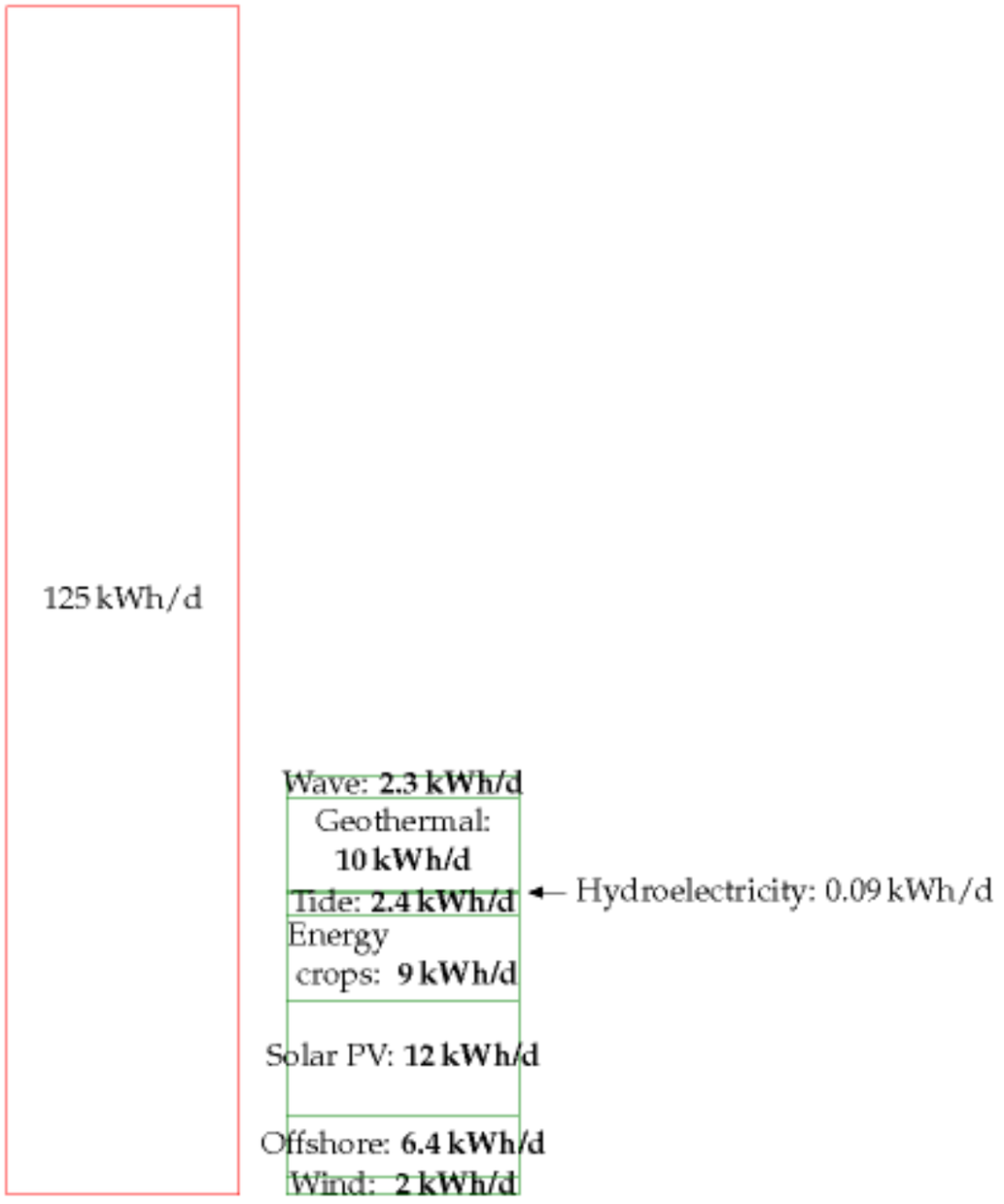
sustainable development commission

The role of nuclear power in a low carbon economy

Paper 2:
Reducing CO_2 emissions - nuclear and the alternatives

An evidence-based report by the Sustainable Development Commission

March 2006

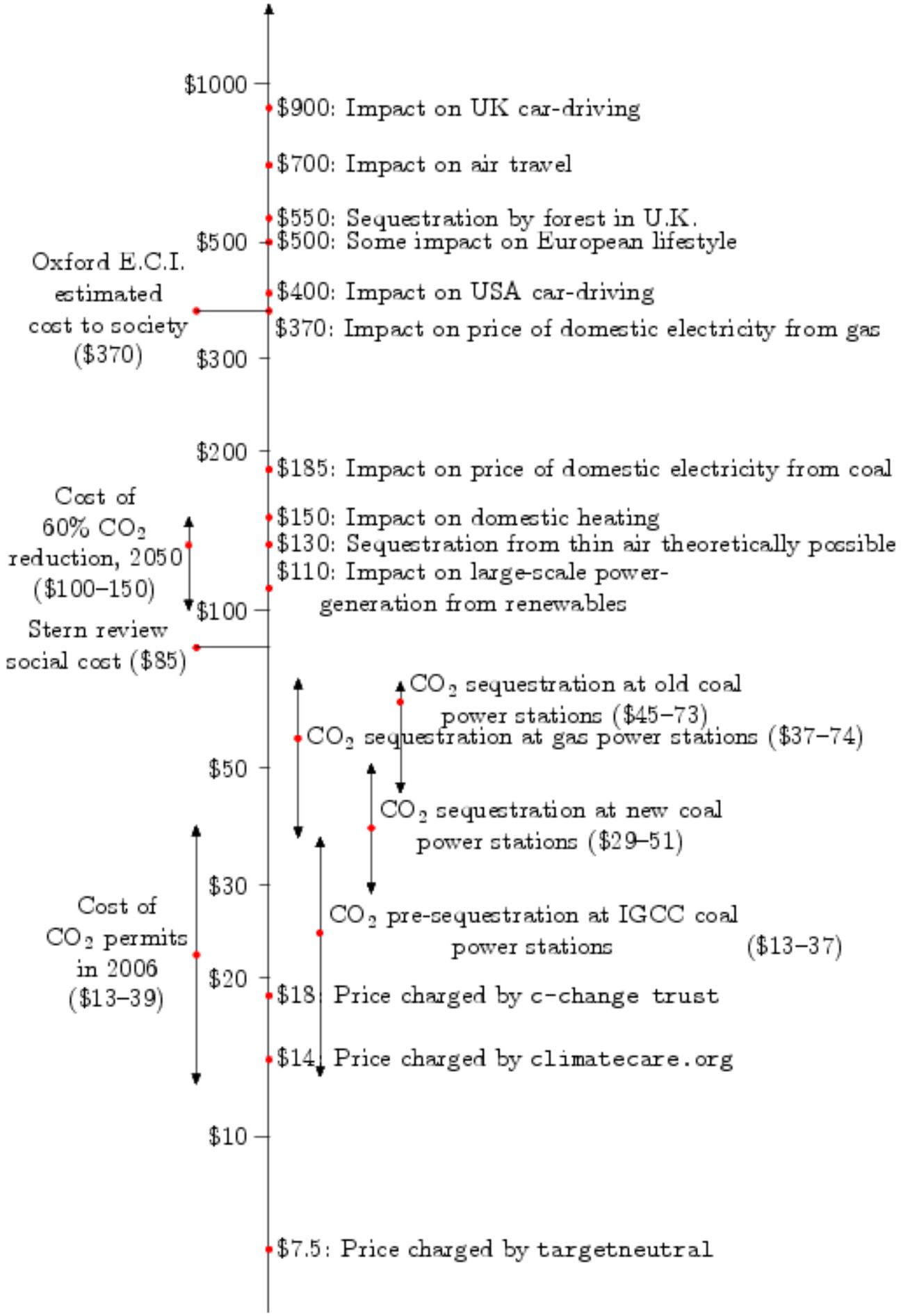


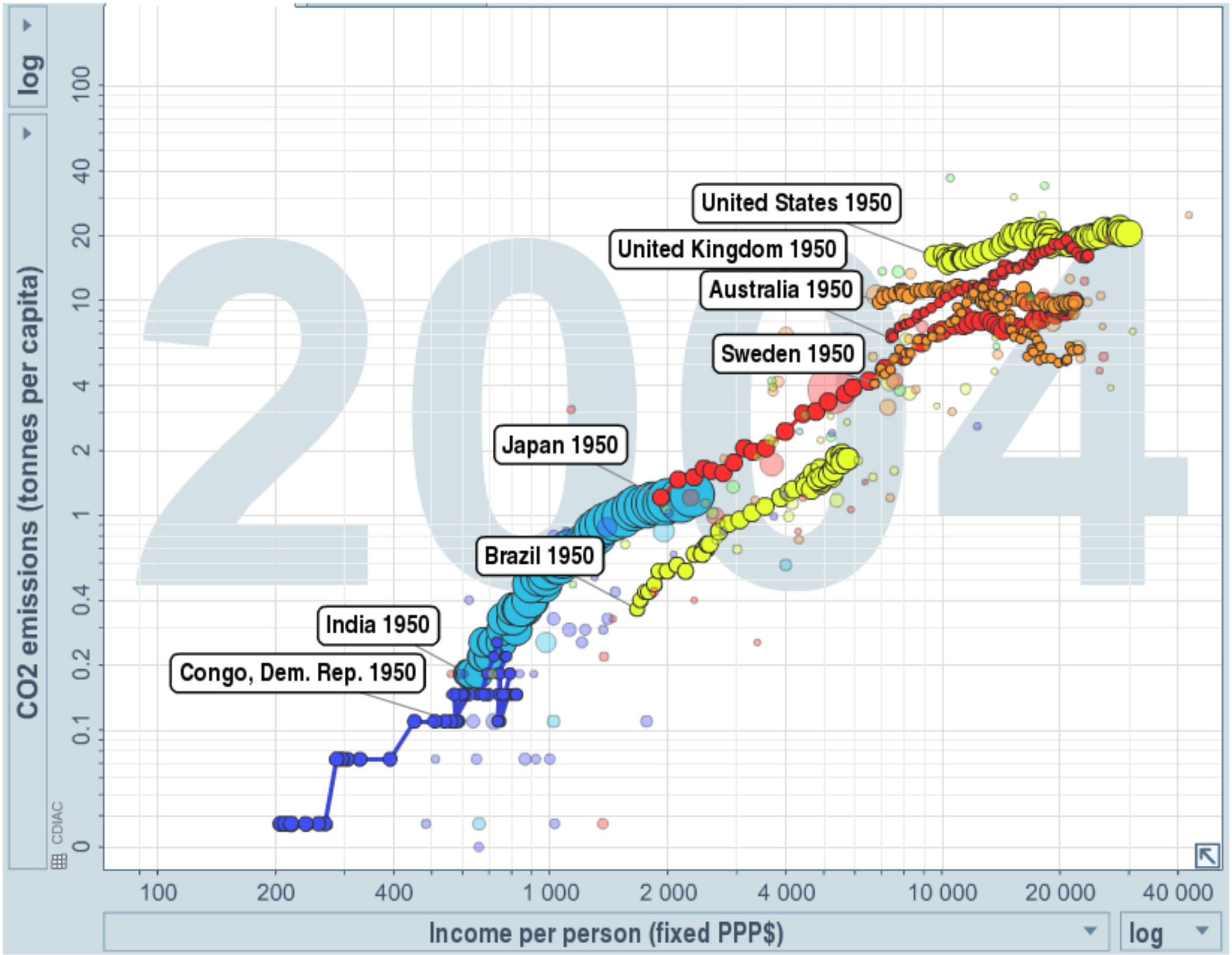
IEE's 'technical potential' is 'an upper limit that is unlikely ever to be exceeded even with quite dramatic changes in the structure of our society and economy'.

Estimates of theoretical / practical resources

My estimates	IEE	Tyndall	IAG	PIU	CAT
Geothermal: **1 kWh/d**	Geothermal: **10 kWh/d**				
Tide: **11 kWh/d**	Tide: **2.4**	Tide: **3.9**	Tide: **0.09**	Tide: **3.9**	Tide: **3.4**
Wave: **4 kWh/d**	Wave: **2.3**	Wave: **2.4**	Wave: **1.5**	Wave: **2.4**	Wave: **11.4**
Deep offshore wind: **32 kWh/d**					
Shallow offshore wind: **16 kWh/d**	Offshore: **6.4**	Offshore: **4.6**	Offshore: **4.6**	Offshore: **4.6**	Offshore: **21 kWh/d**
Hydro: **1.5 kWh/d**		Hydro: **0.08**			Hydro: **0.5**
Biomass: food, biofuel, wood, waste incin'n, landfill gas: **24 kWh/d**	Wastes: **4**	Energy crops, waste: **2**	Energy crops, waste, landfill gas: **3**	Energy crops, waste incin'n, landfill gas: **31 kWh/d**	Biomass fuel, waste: **8**
PV farm (200 m^2/p): **50 kWh/d**					
PV, 10 m^2/p: **5**		PV: **0.3**	PV: **0.02**	PV: **12**	PV: **1.4**
Solar heating: **13 kWh/d**					Solar heating: **1.3**
Wind: **20 kWh/d**	Wind: **2**	Wind: **2.6**	Wind: **2.6**	Wind: **2.5**	Wind: **1**

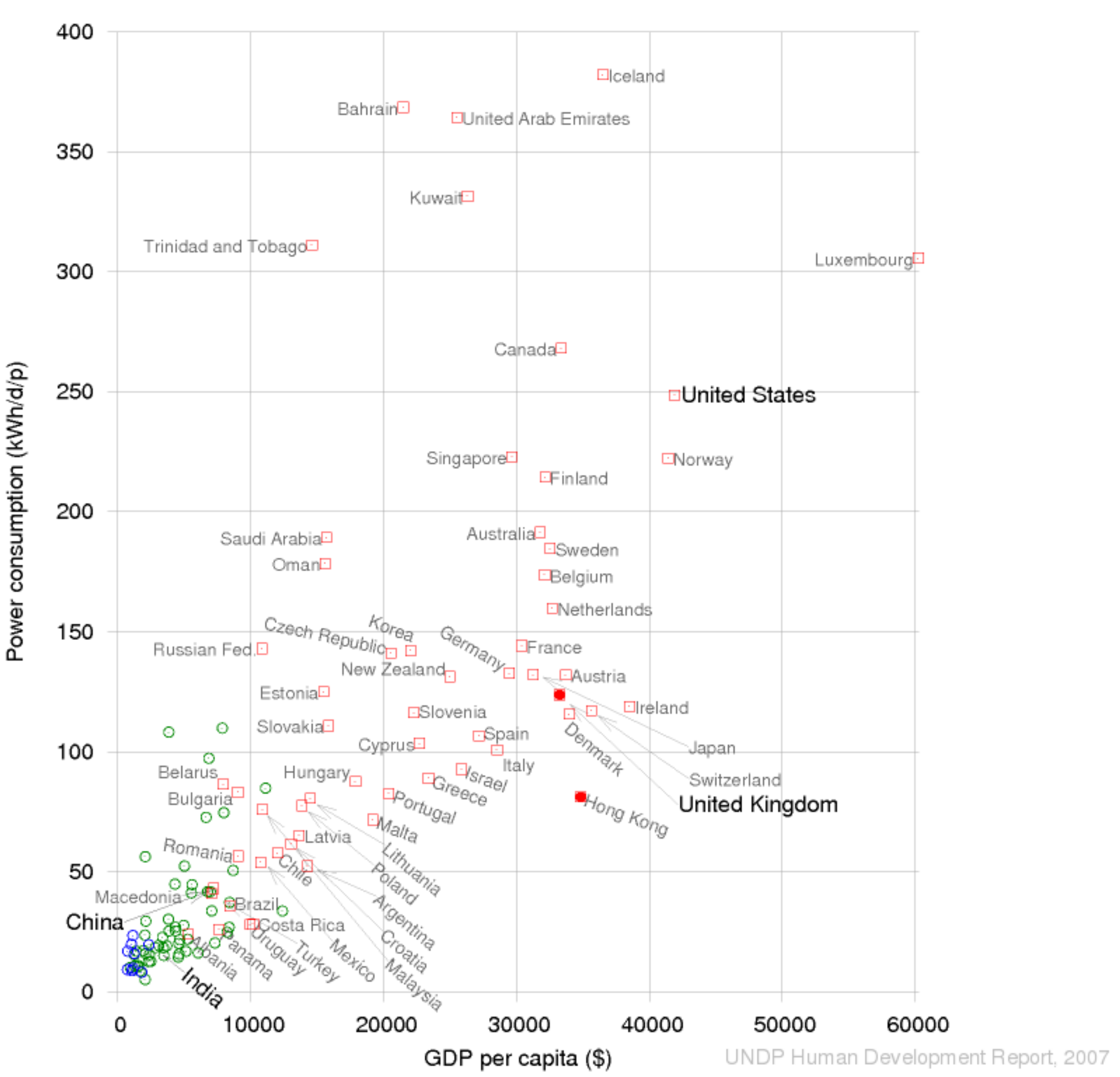
What should carbon cost?





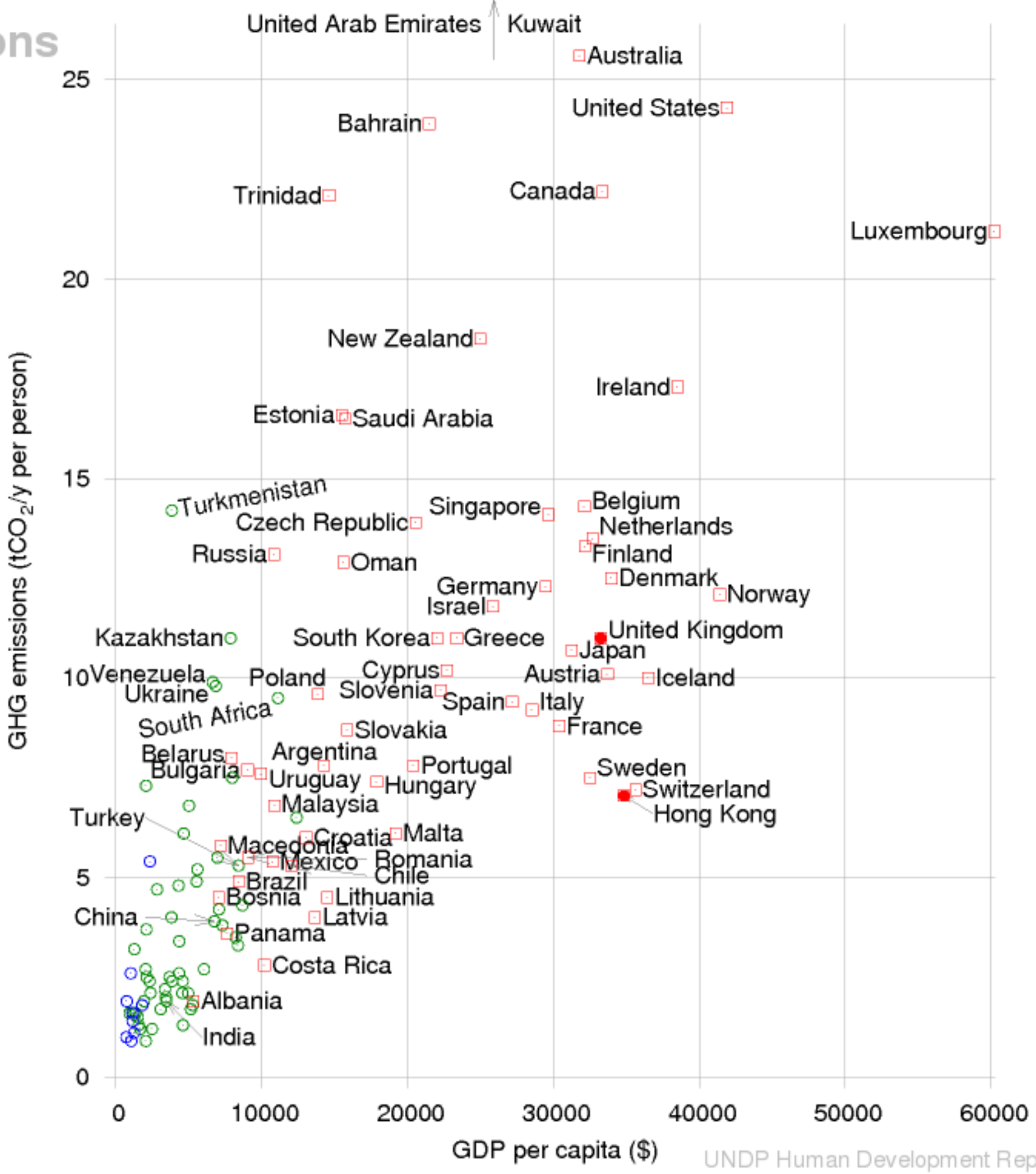
gapminder / google

Energy use versus GDP - linear scale



UNDP Human Development Report, 2007

GHG emissions versus GDP



UNDP Human Development Report, 2007; CAIT, 2007

GHG emissions versus energy use

GHG emissions (tCO_2/y per person)

Energy use (kWh/d per person)

coal

natural gas

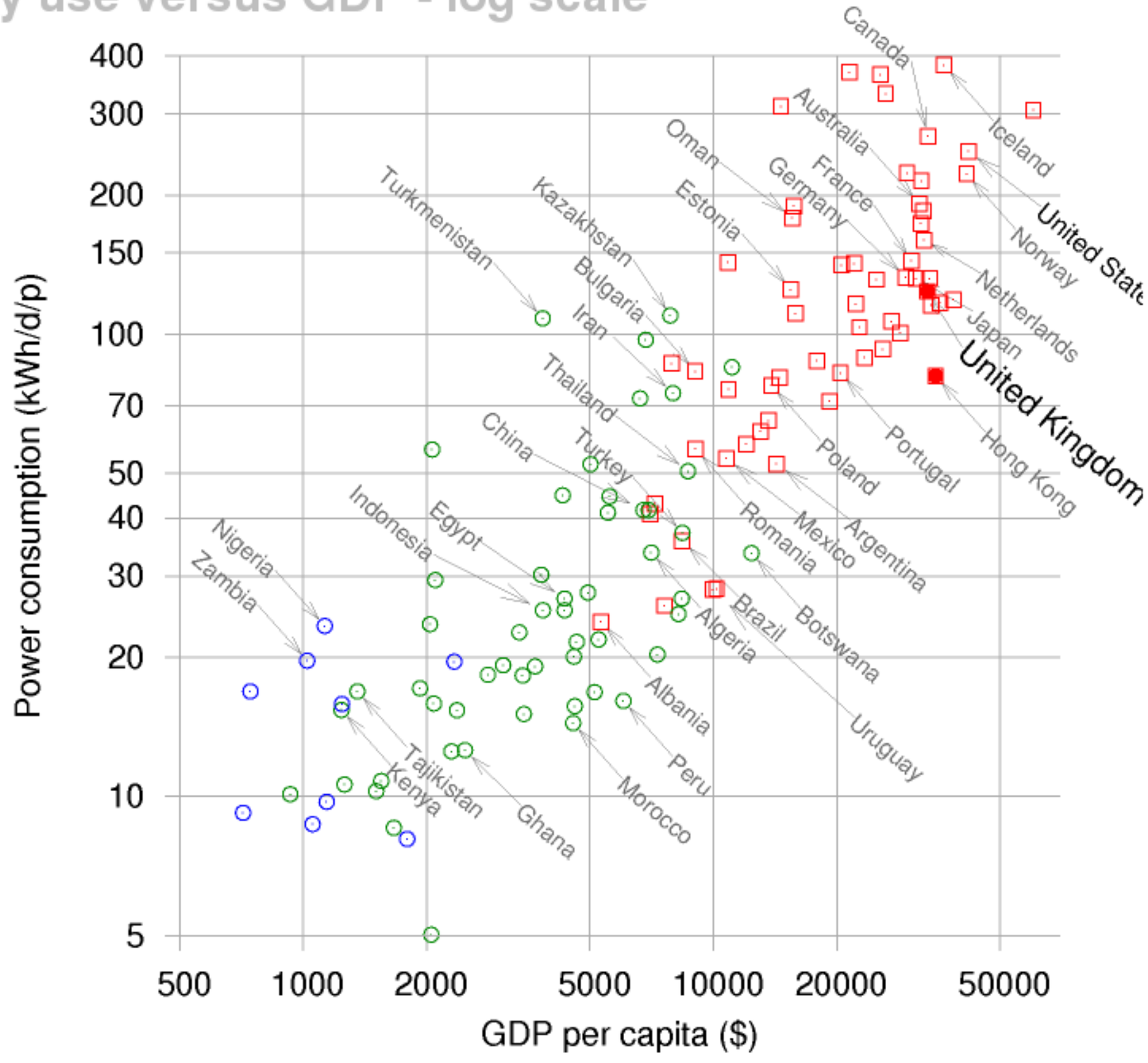
Australia
Kuwait, UAE
United States
Bahrain
Canada
Trinidad and Tobago
Luxembourg
New Zealand
Ireland
Estonia
Saudi Arabia
Czech Republic
Netherlands
Turkmenistan
Belgium
Singapore
Russia
Finland
Oman
Denmark
Germany
Norway
Israel
United Kingdom
Greece
Korea
Japan
Venezuela
Cyprus
Austria
Iceland
Slovenia
Poland
Spain
Italy
France
Slovakia
Argentina
Portugal
Belarus
Uruguay
Bulgaria
Sweden
Uzbekistan
Hungary
Switzerland
Malaysia
Hong Kong
Croatia
Malta
Macedonia
Romania
Chile
Mexico
Brazil
Bosnia
Lithuania
Turkey
China
Latvia
Costa Rica
India
Albania

0
5
10
15
20
25

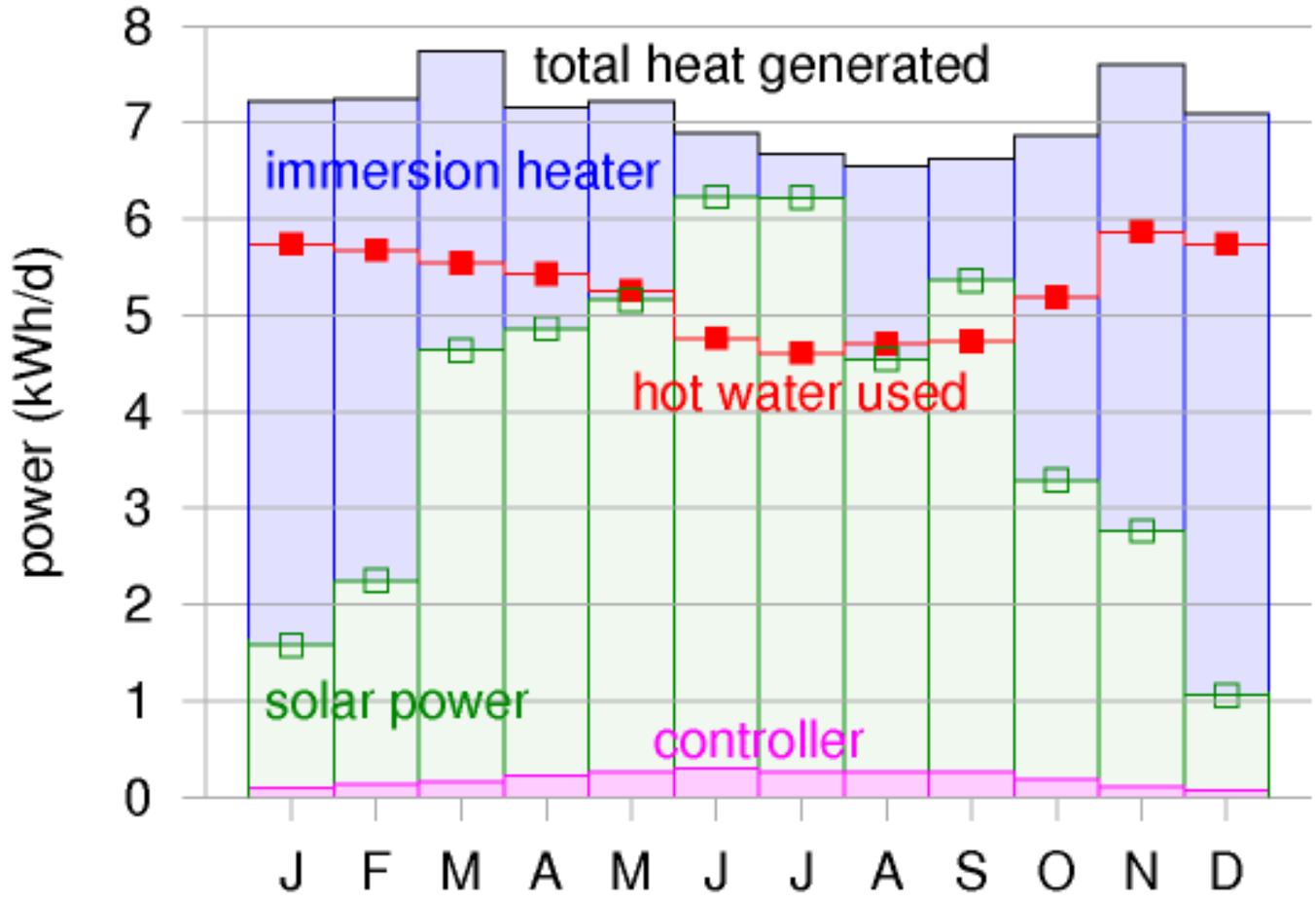
0
50
100
150
200
250
300
350

UNDP Human Development Report, 2007; CAIT, 2007

Energy use versus GDP - log scale



Solar HW



2 kWh/d per person

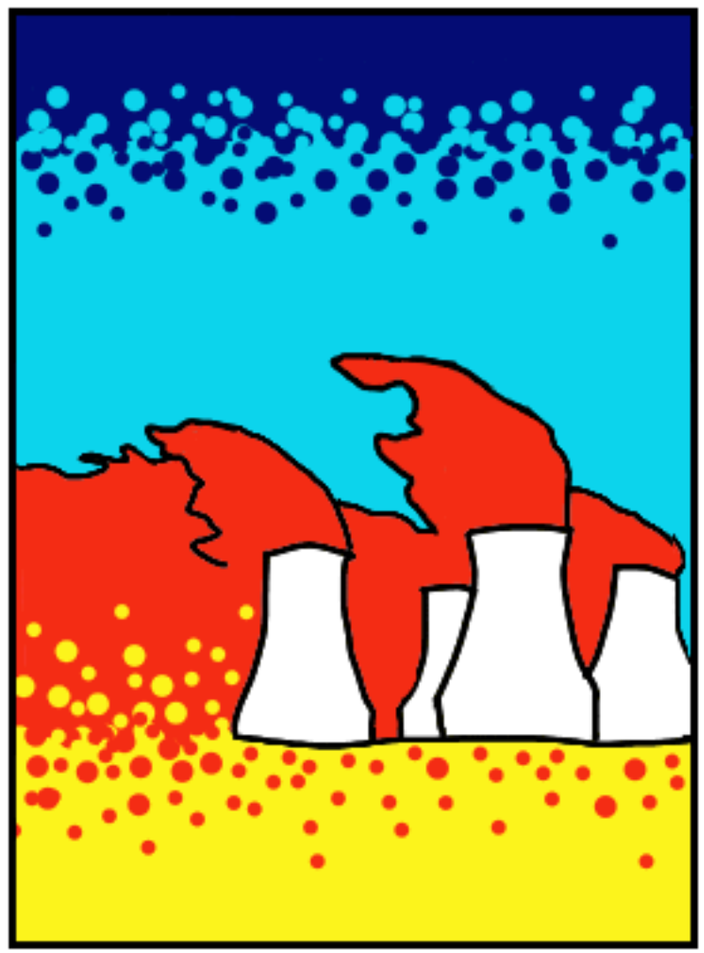
photos by pollok-gonzalo.de

German insulation retrofit

photos by pollok-gonzalo.de

Plan C

- a roadmap to 2050

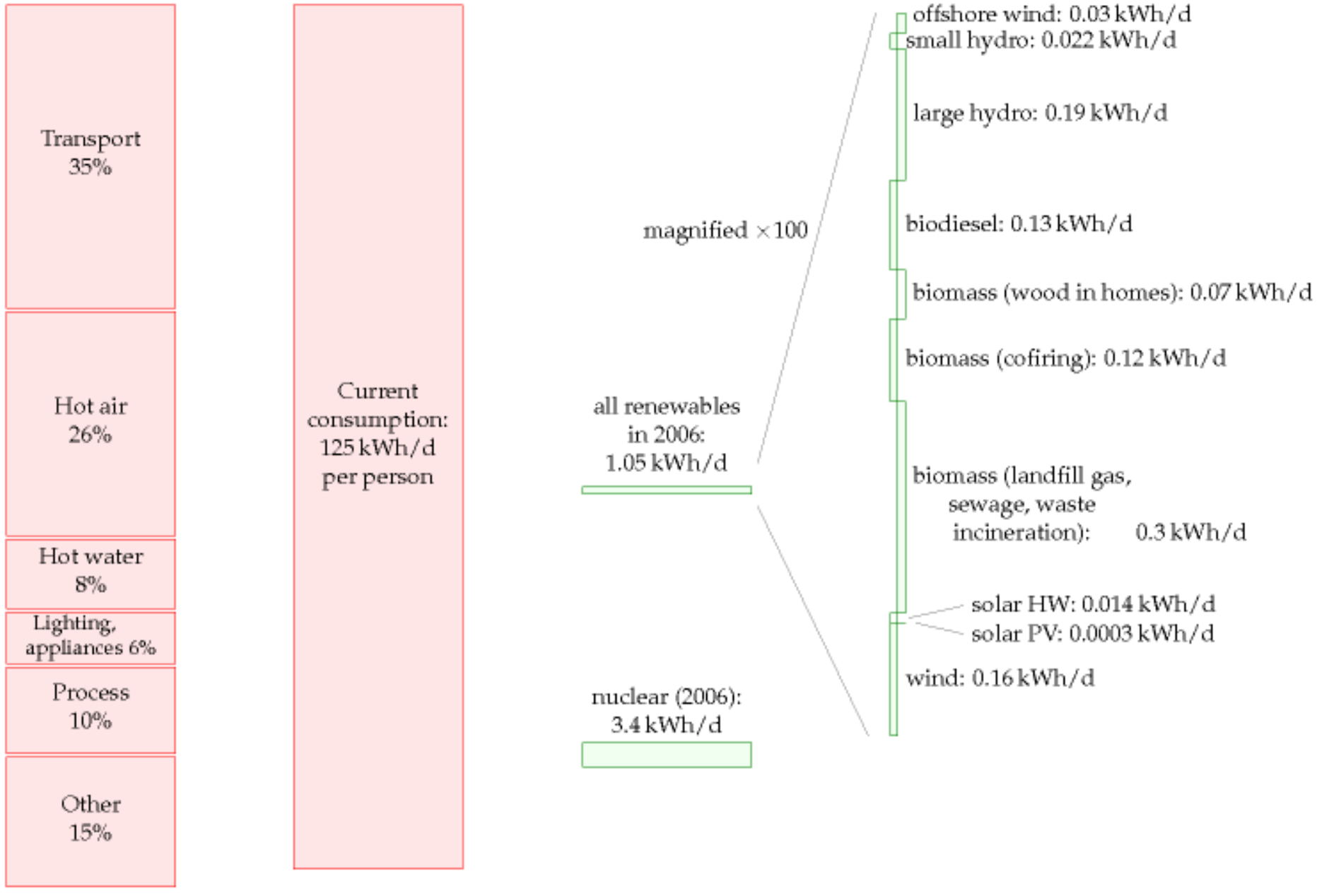


David MacKay FRS

Department of Physics
University of Cambridge

www.withouthotair.com

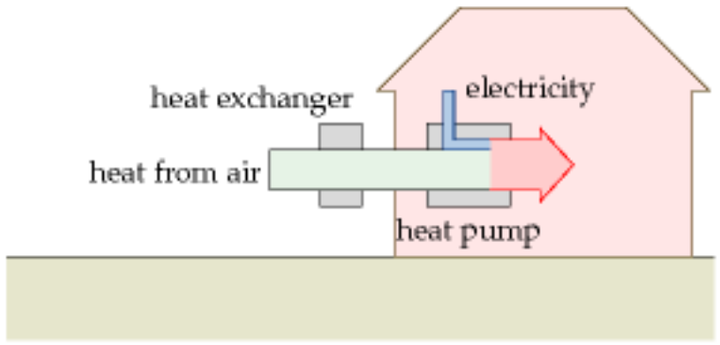
Today's consumption; today's renewables & nuclear

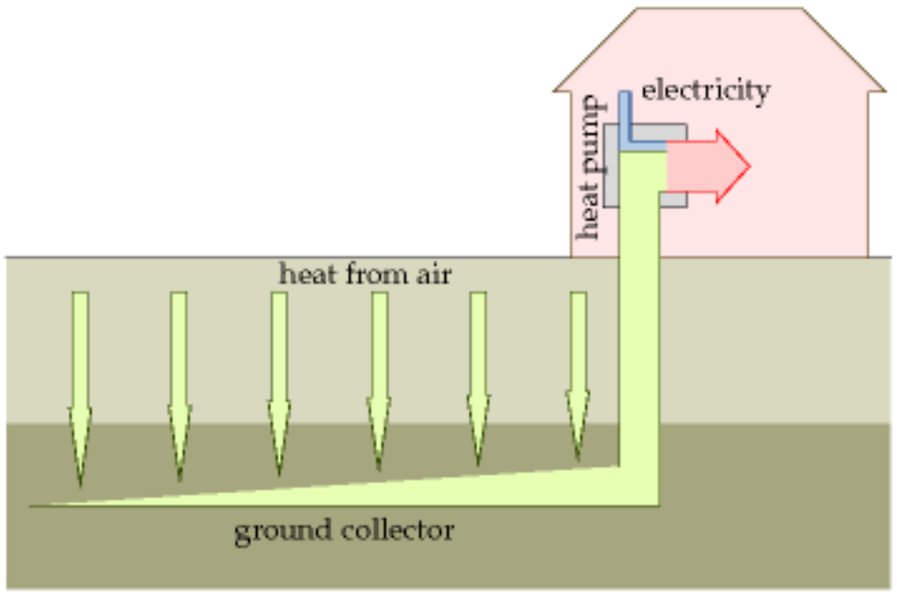


How to get the UK off fossil fuels

- Electrify all transport

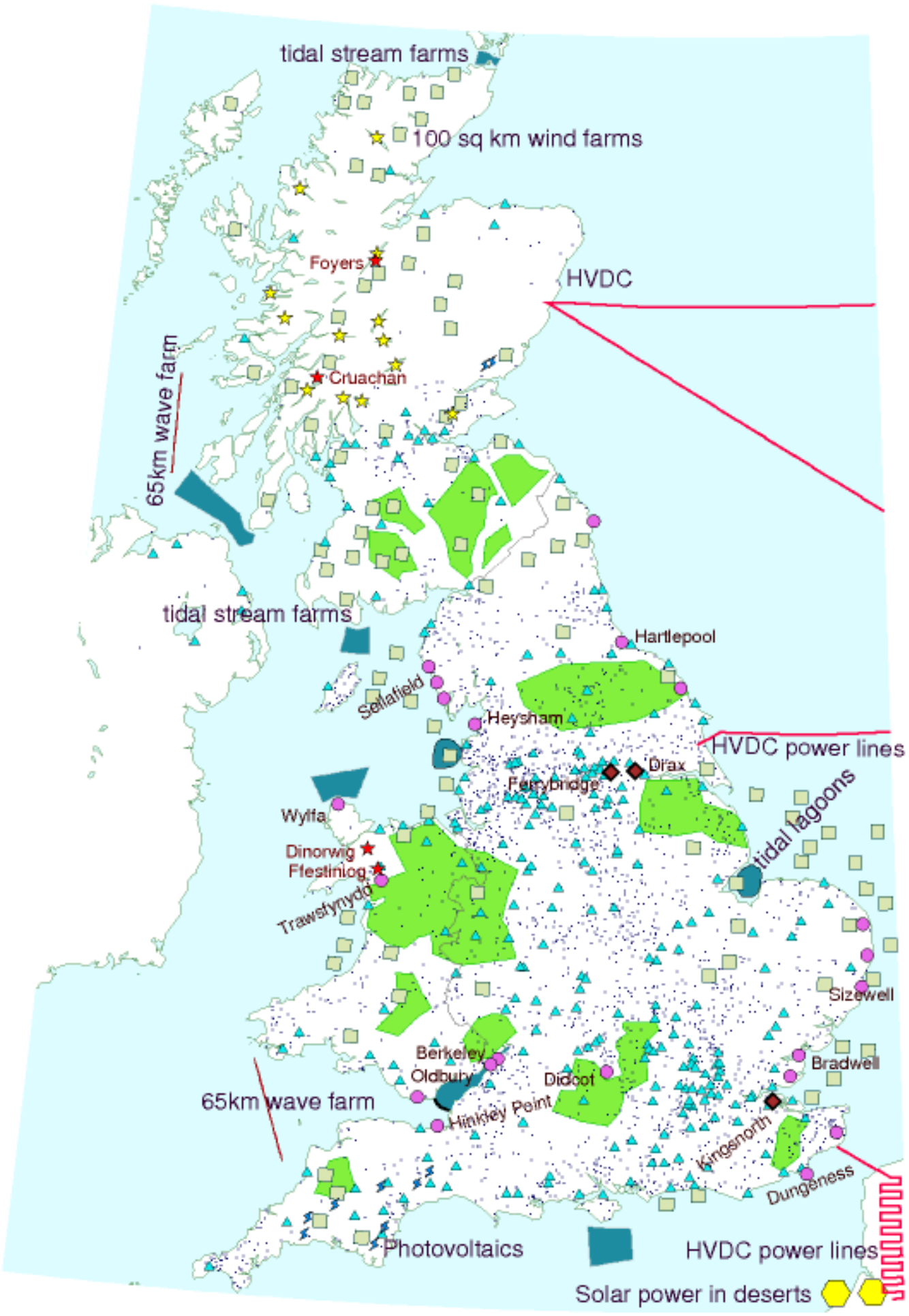
- Insulate all buildings; read all meters
- Electrify all building-heating
  - air-source or ground-source heat pumps
  - (not combined heat and power)





- Triple electricity production

A roadmap to 2050



Wind: **12**

100 GW capacity producing 30 GW average

Clean coal: **1.2**

Tide: **3.7**

8GW, running at 40% load factor

Nuclear: **28 kWh/d**

70 GW

Wave: **0.3**

Hydro: **0.2**

Waste: **1.1**

All municipal waste incinerated, and equal agricultural waste

Pumped heat: **13 kWh/d**

Wood: **3 kWh/d**

Wood-growing: 15% of UK used

Solar HW: **1**

Hot water: 3 sq m per home

PV: **0.3**

1000-fold increase in PV: 0.6 sq m per person

Solar in deserts: **4 kWh/d**

10 GW (average) from Libya and Algeria

- Storage, interconnectors
- Rapidly-adjustable demand
  - Electric vehicles' chargers
  - Heat pumps

A roadmap to 2050

33-fold increase in UK wind; build 2.4GW per year

wind farm area: 2-3% of country onshore and equal area offshore

8GW of clean coal, running at 40% l.f.

tidal stream,
tidal barrages,
tidal lagoons

70GW - seven-fold increase; build 2.1 GW per year

2000 Pelamis, 130km of coastline

all municipal waste incinerated,
and equal agricultural waste

0.6 sq metres per person

1000-fold increase in PV

Wind: **12**

Clean coal: **1.2**

Tide: **3.7**

Nuclear: **28 kWh/d**

Wave: **0.3**

Hydro: **0.2**

Waste: **1.1**

Pumped heat: **13 kWh/d**

Wood: **3 kWh/d**

Solar HW: **1**

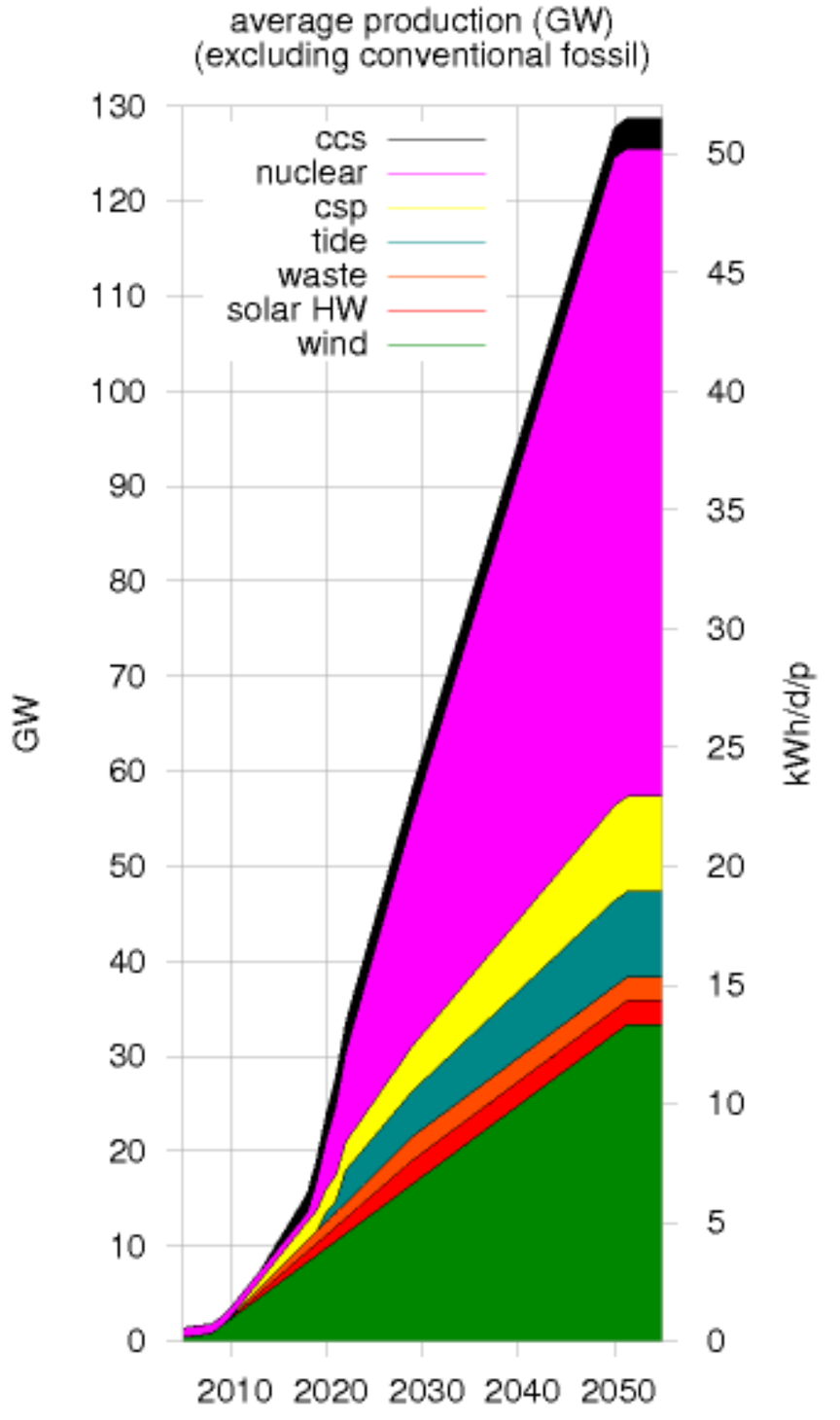
PV: **0.3**

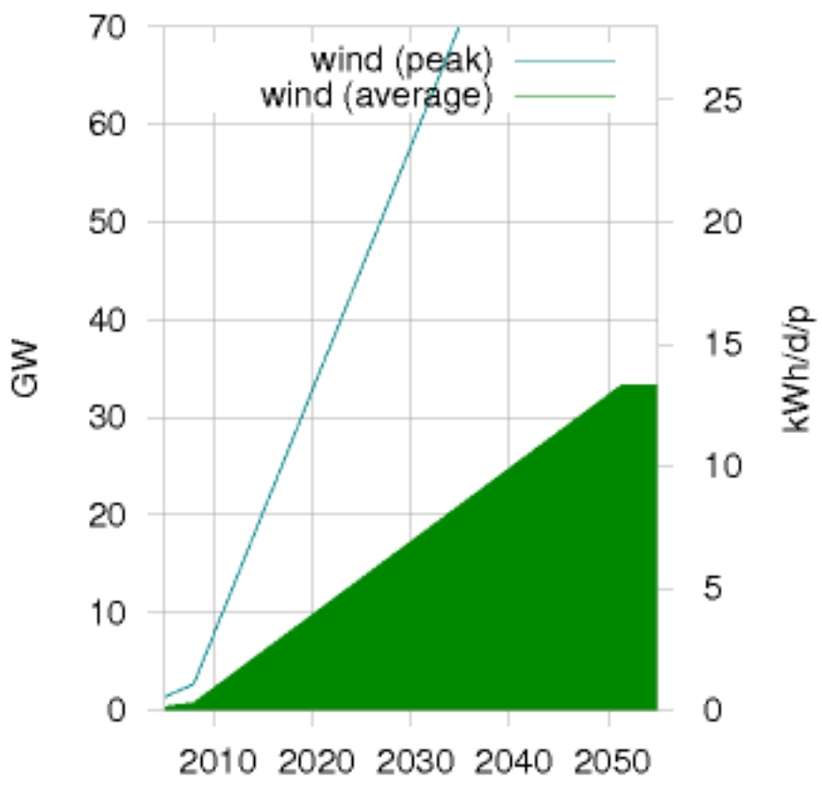
Solar in deserts: **4 kWh/d**

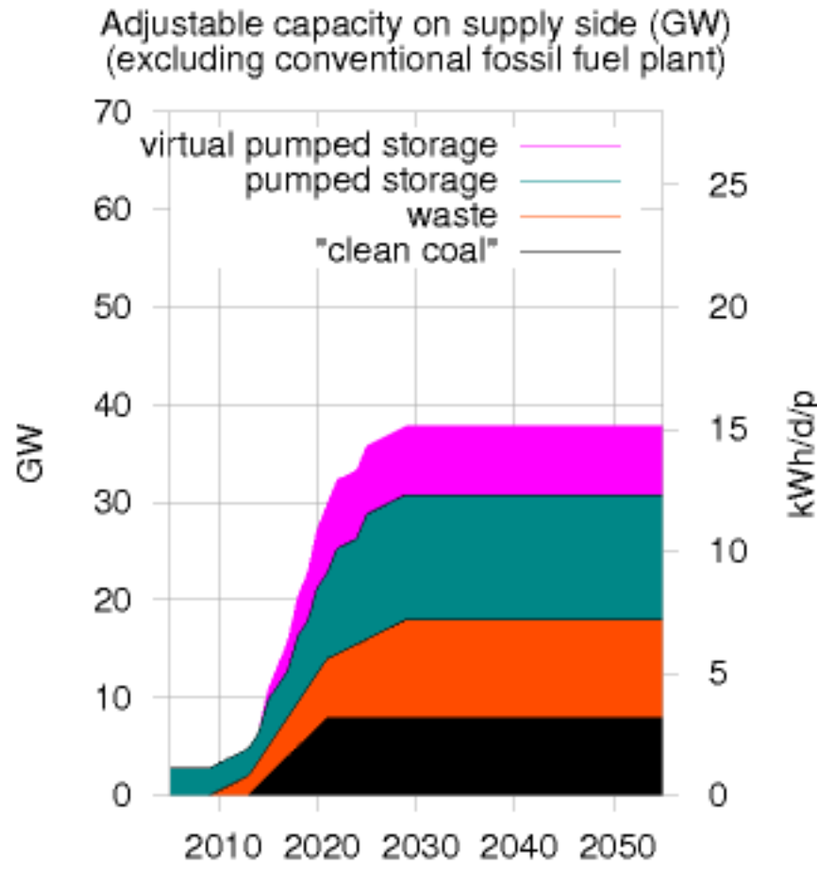
Wood: 15% of UK for forests, willow, miscanthus

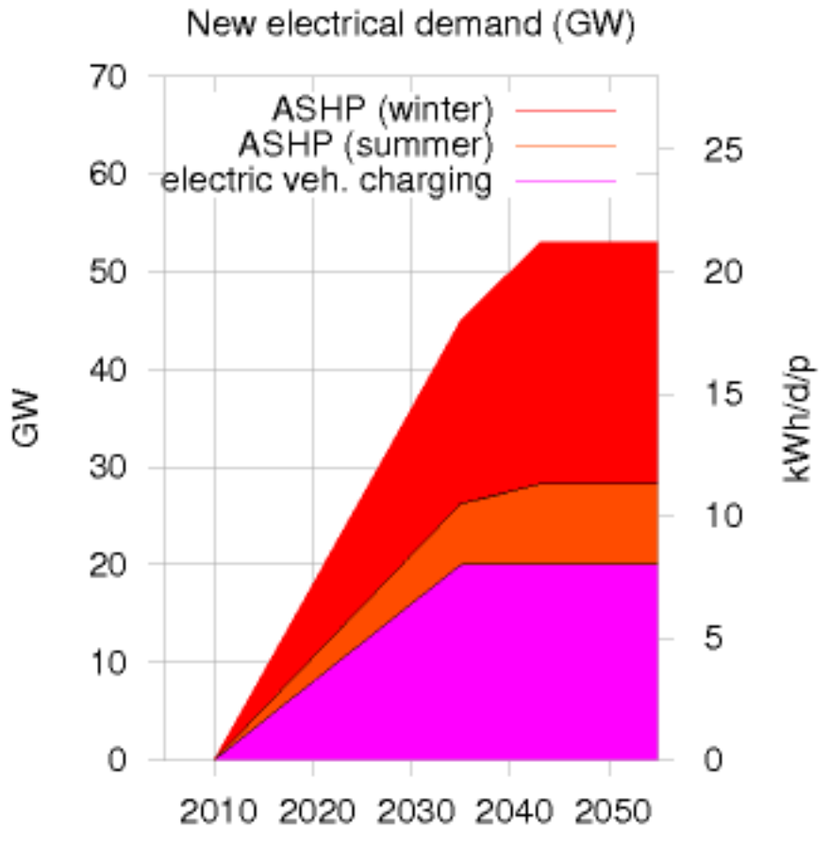
Hot water: 3 square metres per home

Concentrating solar power stations, half the size of London

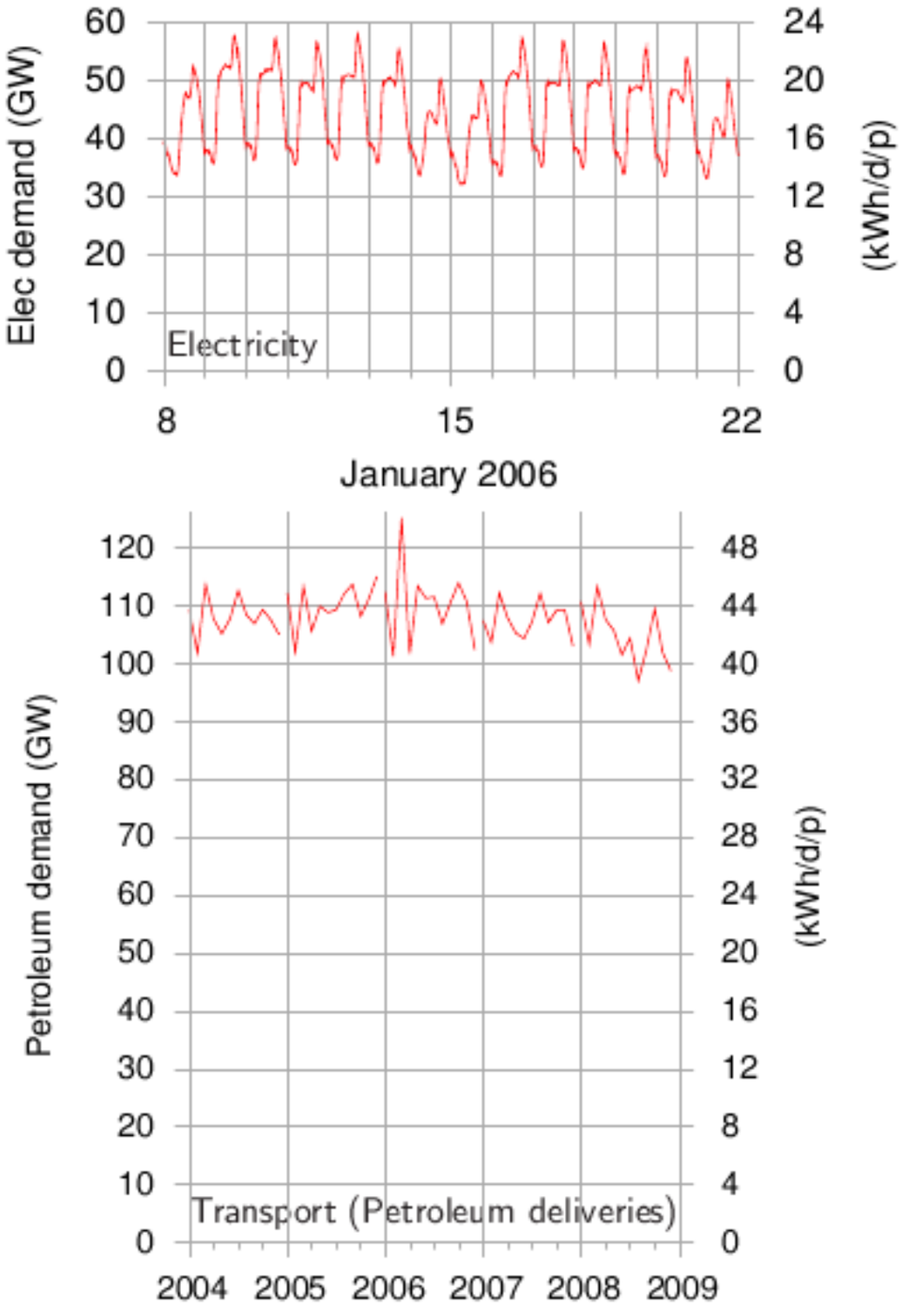

average production (GW)
(excluding conventional fossil)
ccs
nuclear
csp
tide
waste
solar HW
wind
GW
kWh/d/p
0
10
20
30
40
50
60
70
80
90
100
110
120
130
0
5
10
15
20
25
30
35
40
45
50
2010
2020
2030
2040
2050

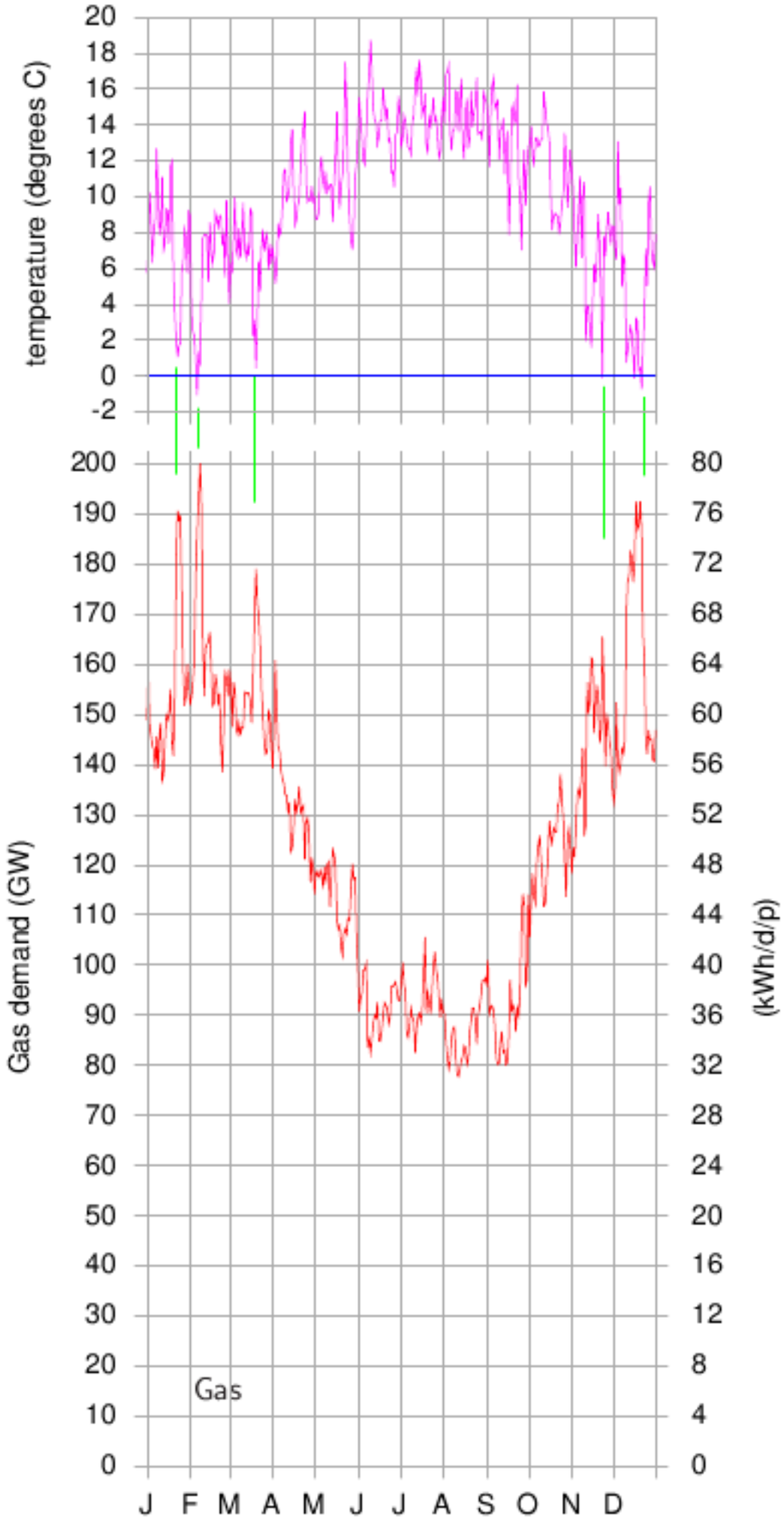

Wind capacity (GW)
wind (peak)
wind (average)
GW
kWh/d/p
0
10
20
30
40
50
60
70
0
5
10
15
20
25
2010
2020
2030
2040
2050


Adjustable capacity on supply side (GW)
(excluding conventional fossil fuel plant)
virtual pumped storage
pumped storage
waste
"clean coal"
GW
kWh/d/p
0
10
20
30
40
50
60
70
0
5
10
15
20
25
2010
2020
2030
2040
2050

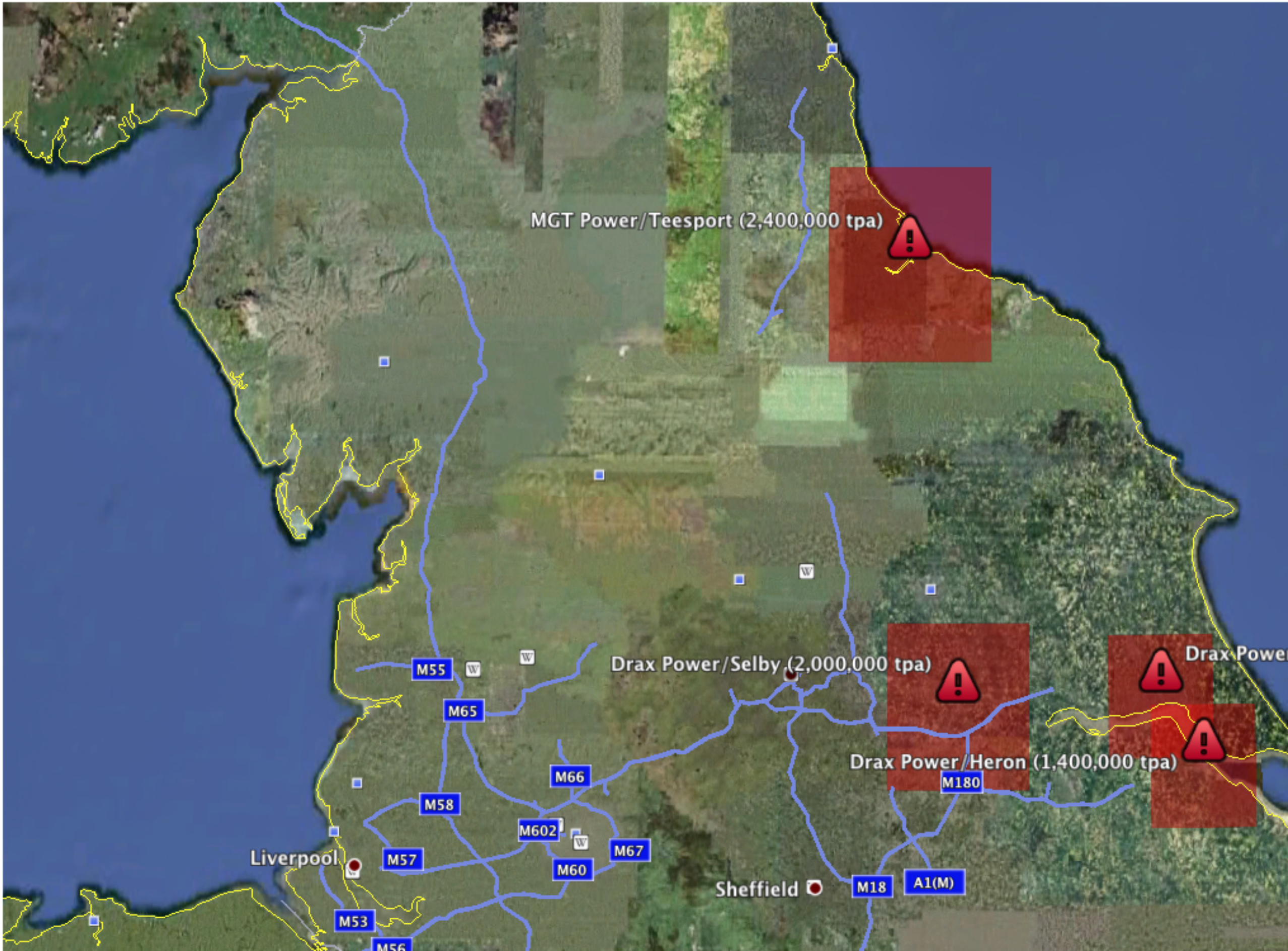

New electrical demand (GW)
ASHP (winter)
ASHP (summer)
electric veh. charging
GW
kWh/d/p
0
10
20
30
40
50
60
70
0
5
10
15
20
25
2010
2020
2030
2040
2050

Transport, heating, electricity; wind





ricity, gas, and
t demand; and
ind (assuming
N of capacity),
ll on the same
vertical scale.


MGT Power/Teesport (2,400,000 tpa)
Drax Power/Selby (2,000,000 tpa)
Drax Power/Heron (1,400,000 tpa)
Drax Power
Liverpool
Sheffield
M55
M65
M66
M58
M602
M57
M67
M60
M53
M56
M180
M18
A1(M)

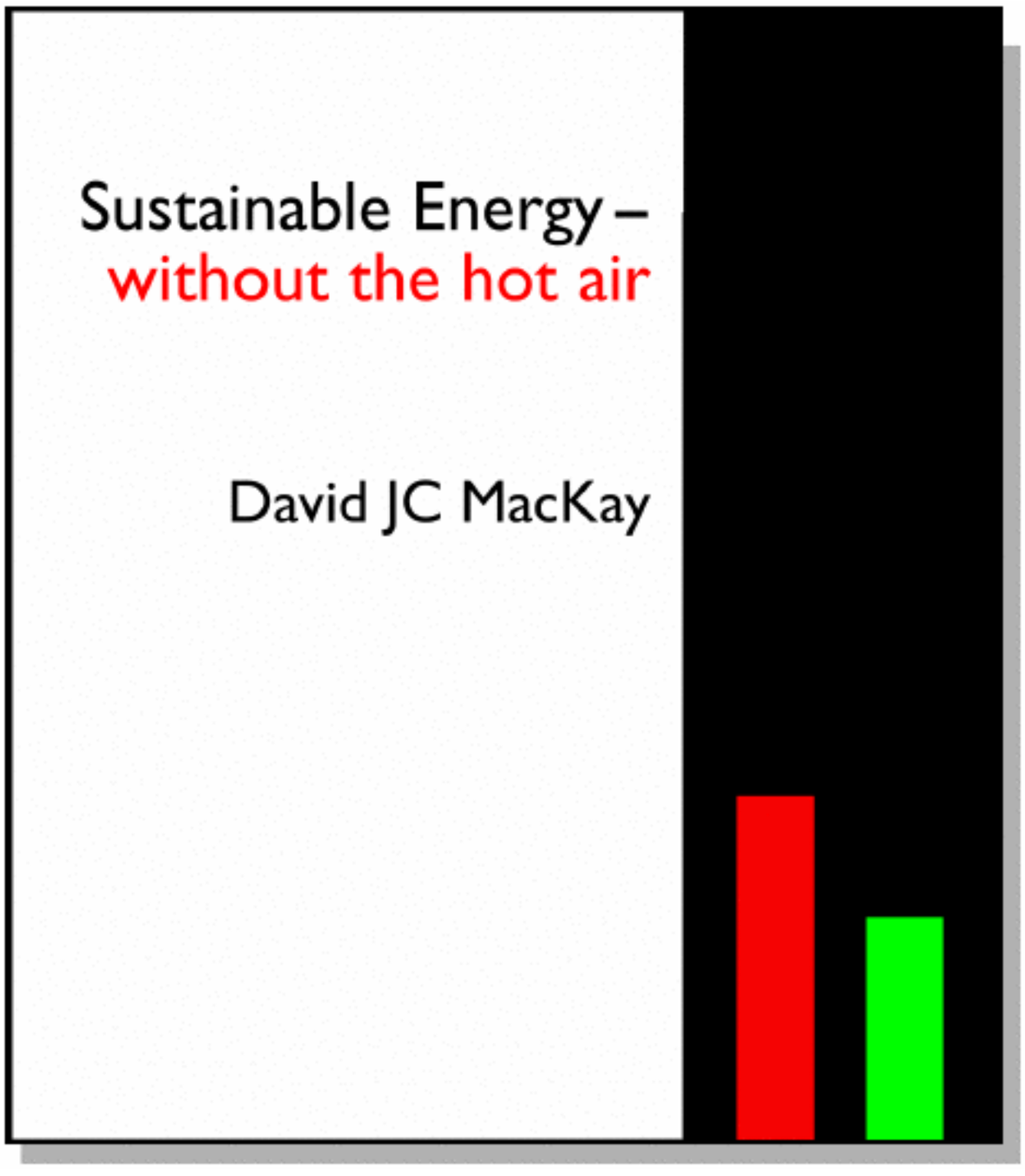
Workshop - part I

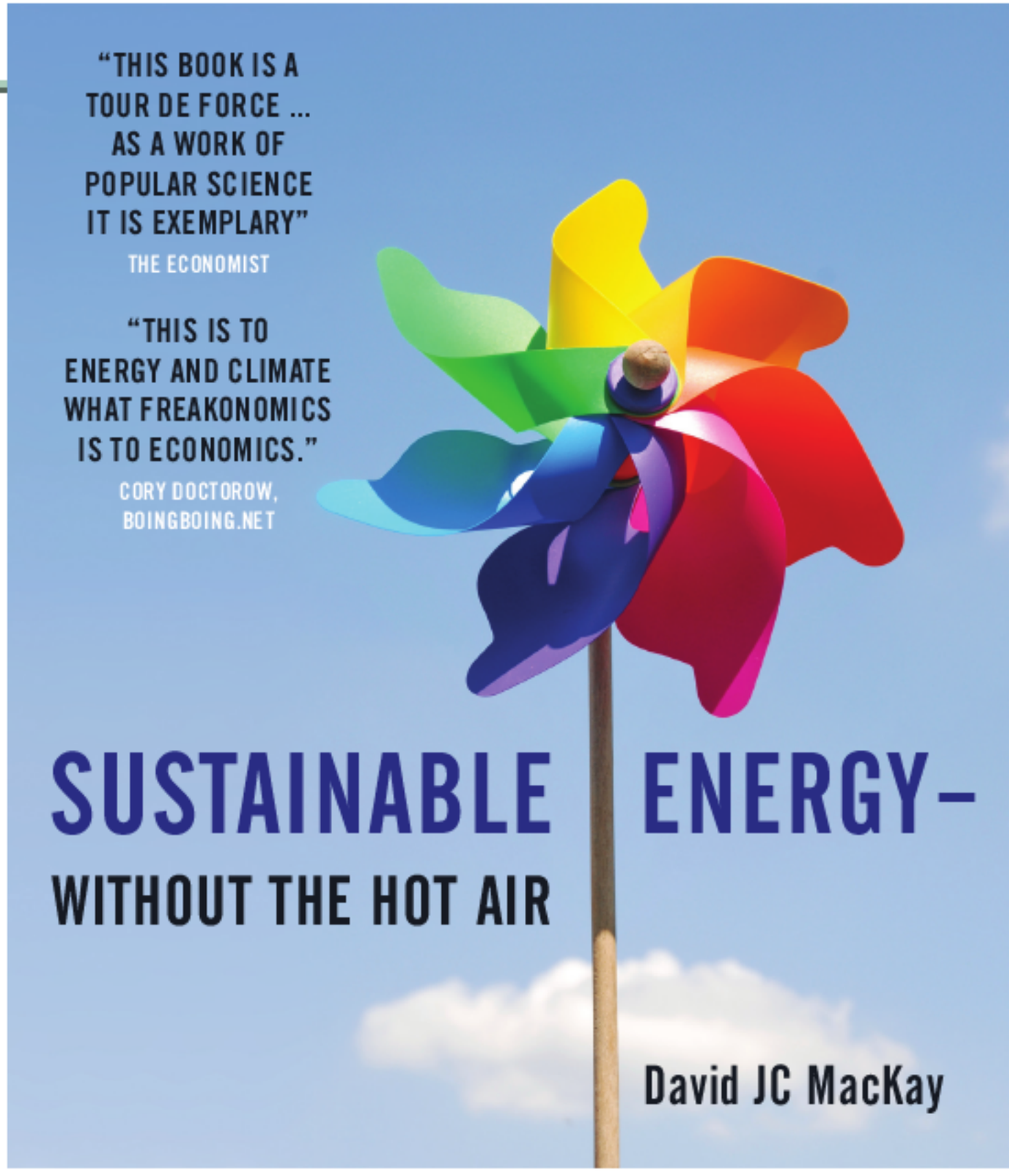
Workshop - part

Workshop - part II

Workshop - part II

This book is free online





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