



International Comparisons: Turbine Densities and Capacity Factors

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Studies on the UK's wind resource are conclusive: "The UK has the best and most geographically diverse wind resources in Europe, more than enough to meet current renewable energy targets".¹

By examining deployment densities per unit of landmass across the European Union this paper shows, however, that the UK's wind resource is massively underutilised in comparison to many of our EU neighbours, with countries with greater population densities or smaller land areas (or both) hosting many times more turbines per 100 km² than the UK.

Introduction

There are no objective criteria of how many onshore wind turbines in the UK would be "too many". What this briefing paper shows however, is that many European countries currently have a much higher density of large wind turbines per 100 km² than the UK (or its constituent parts).² Consequently, these countries reap a higher yield of electricity from wind, despite the UK having 40% of Europe's wind resource.

For example, Denmark has 20 times more large wind turbines per 100 km² than England, which has on average 0.49 large wind turbines per 100 km². It is a similar case with the Netherlands, which has 5.54 turbines per 100 km²,

over 10 times more than England, while also being more densely populated (see Table 2).

These lower turbine density rates, as a rule, translate into a lower contribution of wind to the electricity supply. For instance, Denmark consistently sources around 20% of its total consumption annually, while in the UK as a whole that percentage is around 3%.

If the alternative criterion of watts per capita rates for wind power are taken into account, as opposed to turbine density rates, the UK performs even worse, and is placed towards the bottom of the EU 27 league (see Table 2).

Why numbers count?

The Government's target of 15GW of onshore wind power by 2020 (sufficient to provide around 34 TWh, or approx. 10% of the UK's net electricity consumption), can be realistically achieved using a different number of wind turbines.³

Currently, the UK has 2,664 turbines providing an installed capacity of 3,580 megawatts (MW). This is an average of 1.34 MW per turbine, a 3 fold increase in rated capacity since the first wind farm in the UK was installed at Delabole in 1992, which carried 0.4 MW turbines. This is due to advances in technology, which over the last decade has seen more powerful machines push up the average unit size. Currently, the average power rating of units installed is around 2MW.

Statistics	MW	Turbines	Watts/capita	WTs/100sq km
UK	3,580	2664	54	1.09
latest (Jan 2010)	3,854	2,744	58	1.12
plus 'under construction'	4,978	3,433	75	1.4
plus 'approved'	8,717	4,979	132	2.03
2020 scenario	15,000	10,000	212	2.44

Looking at future trends, even when those wind farm projects with planning permission and in construction are taken into consideration, the turbine density in the UK will still be around 2 turbines per 100 km².

Beyond mid decade, Table 1 assumes an average capacity of around 1.5MW per turbine in 2020, given the likelihood of some existing turbines being repowered, and the total onshore number coming to around 10,000. Even in that scenario the UK total would be well below that of many of our EU neighbours both in terms of watts per capita or turbines per km/sq. Furthermore, this is without taking into account the increases in number of turbines in other countries.

Objective measurement levels of deployment

So far, limits (or scenarios) of deployment in the UK have been set according to what is deemed acceptable given public attitudes towards renewable energy, and wind energy in particular, and also taking into account constraints of physical geography. An example of this approach is the Department of Energy and Climate Change's (DECC) "2050 Pathway's Analysis" deriving its approach from Professor David Mackay's work.⁴

Other scenarios,⁵ such as the Government plan to fulfil the

CONVERSION TO SQUARE MILE

TO GET THE TURBINE DENSITY PER SQUARE MILE, MULTIPLY THE NUMBER OF TURBINES BY 2.59. FOR INSTANCE 0.49 TURBINES PER 100 SQUARE KILOMETERS IS 1.27 TURBINES PER 100 SQUARE MILES.

UK's obligation to source 15% of the country's energy from renewables by 2020, has taken into account parameters such as deployment rates and availability of investment. However, resulting figure of 15GW for onshore wind by 2020 should not be understood as the physical limit for onshore deployment, nor does it recommend a number of turbines.

Public attitudes

The question of 'how many turbines we could have installed in the UK' is often interpreted to mean 'how many turbines would the general public be ready to accept'. In other words, the question becomes not one of limits of social or physical geography, but one of public attitudes to wind energy.

The assumption is that the UK's high percentages of refused planning applications for wind farms are indicative of negative attitudes towards wind power. However, polls indicate public support for wind farms. From 2006 to 2009 DECC published an annual poll on attitudes towards renewables. It is indicative that the percentage of people disagreeing with the statement that 'they would be happy to live within 5km (3 miles) of a wind power development' has actually fallen from 24% in 2006 to 21% in 2009.⁶

Undeniably, though, wind turbine density is lower than in other European countries, and a host of explanations were put forward to account for this: from the impact of the discovery of North Sea oil on the UK's renewable sector; the fact that the UK is a densely populated country; a greater reliance on community based development models; to the fact that other countries have built much larger wind industry work forces, which lobby for further deployment. For instance, almost 1% of Denmark's total working age population is employed in the country's wind industry.⁷ In the UK this per cent is 0.0003%.⁸

European comparisons: onshore turbine densities and watts per capita

It is often suggested that Denmark has the highest density of wind turbines in the world, but it is instructive to quantify exactly what this means, and to make comparisons with other European nations. These comparisons are made in Table 2, which covers onshore wind only. Turbine numbers are less readily available than installed capacities, but the data are the latest available between January and August 2010. The analysis confirms that Denmark has by far the

highest turbine density; at just under 11 turbines per hundred square kilometres it is nearly double the German figure of six turbines per hundred square kilometres and 10 times the UK figure of 1.1 turbines per hundred square kilometres. The UK is eighth in the table, with the Netherlands, Spain, Portugal, Italy and Ireland all ahead.

The picture for installed capacity per head of population is somewhat different. Denmark, once again, heads the table, with 518 W per capita, followed by Spain (425), Ireland (310) and Portugal (317). In Table 2, the UK is in the last place in terms of watts per capita.⁹

	Latest MW	Turbines	Area, sq km	Watts/capita	WTs/100sq km
Denmark	2851	4675	43075	518	10.85
Germany	26302	21226	356840	320	5.95
Netherlands	1999	1880	33940	121	5.54
Spain	19450	17100	504880	425	3.39
Portugal	3357	1844	91630	317	2.01
Italy	5133	4930	301245	86	1.64
Ireland	1381	1105	68895	310	1.60
UK	3580	2664	244755	58	1.09
Greece	1185	1320	131985	105	1.00
Austria	1001	620	83855	125	0.74
France	4690	2600	543965	75	0.48
Sweden	1560	1700	449790	168	0.38

UK comparisons

Scotland leads the way within the UK when it comes to wind energy deployment. As Quarter 3 2010 statistics have indicated Scotland now gets approximately 15% of its electricity from wind and 30% from renewables. Despite recent developments the average turbine density for Scotland alone is well below that of European leaders.

On the other hand, England's rating both in terms of watts per capita and number of wind turbines is at the bottom of the European league. With 0.49 turbines per 100 km² (1.27 mi²) England is also lagging within the UK.

As Table 1 shows, the 2020 scenario calling for around 10,000 turbines will increase the average number of turbines per 100 km² to 2.44, which is just above the current rate in Portugal and still significantly less than the current rate in Spain.

Wind energy: productivity comparisons

It is often said that the UK's low wind turbine density is particularly unfortunate as the country, and the British Isles in general have the best wind resource in Europe. What does this exactly mean?

Table 3: UK turbine densities and watts per capita current

		Turbines	Area, sq km	Watts/capita	WTs/100sq km
	MW				
England	821	644	130395	16	0.49
Scotland	2361	1354	78775	454	1.72
Wales	380	504	20767	127	2.43
NI	310	218	14120	172	1.54
UK	3872	2720	244057	58	1.11

When making inter-country comparisons, a full year of electricity production data is clearly required for calculation of realistic capacity factors but a representative figure for installed capacity can be difficult to establish, simply because rapid growth in many places means that the capacity at the end of the year may be substantially different from the capacity at the beginning of the year. Strictly speaking, a weighted-average figure should be used, but this demands information about the commissioning dates of all wind farms. Another aspect to be considered is diversity or geographical spread of wind resource.

A simpler, but less accurate, approach is to base capacity factor calculations on the average figure based at the "start" and "end of year" capacity figures. The UK Department of the Energy and Climate Change also looks at output data from wind farms that were operational during the whole of the year, but this requires more detailed information that is not generally available.

Despite these caveats, an increasing quantity of information is becoming available, and Table 1 includes information from a number of sources for the year 2009, which is the most recent year for which reliable International Energy Agency (IEA) statistics exist. Also, in this table, the figures for installed capacity have been taken from the journal *Wind Power Monthly* and production data from the IEA.

In terms of broader worldwide comparisons, American figures are very close to the UK, with New Zealand and Australia the being the only 2 countries in the world with a distinctly higher load factors.

Looking at worldwide overall capacity factors, they currently stand at an average of 24%. This estimate is based on taking into account 63% of the world's installed wind energy capacity (See Table 4). This again shows that the UK outperforms the average with 28.7%. As total worldwide capacity has by the end of 2010 reached over 165,000 MW, the corresponding worldwide electricity production from wind may be expected to be around 347 TWh. To set this in context, it is slightly more than total electricity consumption in the UK in 2009.

Concluding remarks

Although capacity factors have their limitations and do not necessarily provide a basis for comparisons between individual machines, country-wide data enable reasonably accurate estimates of the electricity-generating potential of the wind plant to be made. Broadly speaking, the higher the capacity factor (but also taking into account factors such as geographical spread), the more windy the country is. However, on the basis of the data in Table 4 a provisional conclusion can be drawn that an average wind turbine in the UK yields 50% more electricity than a wind turbine in Germany, based on the comparison of load factors.

However, the average turbine density in the UK is about one tenth of the Danish figure and one fifth of the German. When onshore installed power per head of population is calculated, the UK figure of 61 W per capita is, once again, well behind the market leaders (Spain, Denmark and Germany).

Table 4: Electricity production from wind energy and the corresponding country-wide capacity factors in Europe

	Capacity in MW		Production, TWh	Capacity factors
	Start 2009	Start 2010	2009	2009
Ireland	1053	1270	2.95	29.0
UK	3334	4058	9.3	28.7
Greece	985	1087	1.99	21.9
Portugal	2833	3535	7.57	27.1
Sweden	1021	1560	2.49	22.0
Denmark	3180	3480	6.72	23.0
Netherlands	2216	2221	4.59	23.6
Finland	143	146	0.28	22.1
Austria	995	995	2.45	28.1
Spain (incl. Canary Is)	16740	19149	36.19	23.0
France	3387	4538	7.75	22.3
Germany	23903	25777	37.81	17.4
Italy	3736	4850	6.09	16.2

- 1 Sustainable Development Commission, Wind Power in the UK, 2005, page 6. See also Troen, I., Petersen, E.L., European Wind Atlas, Riso National Laboratory Roskilde, 1989.
- 2 The industry criterion of a large or utility scale wind turbine is a device with an installed power rating of over 100KW and total height of over 50 metres. See for instance RenewableUK, Generate your Own Power, 2010, page 2&3.
- 3 The Government target, in step with EU 2020 renewable energy targets, is to source 15% of all energy by 2020 from renewables. The headline scenario calls for 15GW of onshore wind (amongst other technologies) without specifying the number of turbines. DECC, 2010, National Renewable Energy Action Plan for the United Kingdom.
- 4 2050 Pathways Analysis suggests a practical maximum of 20,000 onshore wind turbines for the UK. See also D.Mackay, Renewable Energy Without the Hot Air, 2009.
- 5 DECC, 2010, National Renewable Energy Action Plan for the United Kingdom
- 6 GFK NOP Social Research, September 2009, published by DECC
- 7 See the Danish Wind Energy Association's website, www.windpower.org/en/
- 8 RenewableUK, Working for a Green Britain, 2011
- 9 Population statistics on which watts per capita numbers are based in this report are taken from Eurostat (epp.eurostat.ec.europa.eu) and the Office for National Statistics (www.statistics.gov.uk)