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The hidden fuel costs of wind generated electricity.

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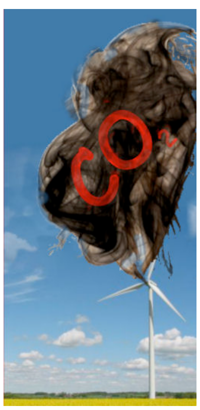
Summary



Wind generated electricity requires back-up capacity of conventional power stations. This capacity is required to deliver electricity to consumers when wind supply is falling short. To have the non-wind power stations ramp up or down to compensate for the stochastic wind variations causes extra efficiency loss for such power stations. How much efficiency is lost in this way and how much extra fuel is required for this extra balancing of supply and demand is unknown. In this article we attempt to make an educated guess.

The extra fuel required for the efficiency loss must be added to the fuel required for building and installing the wind turbines and the additions to the power cable network. While these extra requirements may be too small to notice when the installed wind power is a small fraction of the total capacity, matters change when wind capacity becomes significant. Based on the German situation with 23 GW of installed wind power, we show that it becomes doubtful whether wind energy results in any fuel saving and CO_2 emission reduction. What remains are the extra investments in wind energy.

Introduction.

Wind energy comes for free, but it does not follow that electricity generation using wind is also free. The hardware costs money and energy to build. The energy required for this is typically derived from fossil sources. More importantly, one needs to maintain a conventional back-up power generator capacity roughly equal to the installed wind power capacity.

The wind may be free of charge, but it is not provided in the desired doses. Wind varies. The variations do not match the electricity demand. Because there is as yet no economically viable method to store electricity, the variations in wind generated electricity levels that do not match demand levels have to be met by adjusting the output of conventional power stations. In his recent thesis[1] Ummels concludes on the basis of computer modelling studies that such adjustments can be made "without problems" even when wind would generate electricity equivalent to 33% of the Dutch demand.

Others are less positive. We quote from the study[2] "De regelbaarheid van elektriciteitscentrales" (The adjustability of electric power stations) which was published in Dutch in April 2009:

"Increasing the rate of reaction of the power station assembly can only be achieved by using inefficient open-cycle gas turbines or by cannibalising on the reliability and lifetime of large and efficient power stations. This means that flexibility translates into inefficiency and higher fuel consumption and CO_2 emission than one can expect on the basis of average efficiency. (our note: i.e. without the additional requirements of adjusting for wind fluctuations).

A further quote:

"Controlling the output level costs money: every output variation of a power station creates extra wear. This reduction of useful life is larger as the rate of output change increases. In addition, variations in output cause reduced energy efficiency which translates into additional costs and increased environmental impact." (translation: ours).

While this report identifies the problem of reduced efficiency, it does not indicate the magnitude of the efficiency decrease, nor the amount of the required additional fossil fuel use. Both studies only provide assumptions on the effect of increased wind turbine power, but no field data.

The Dutch wind energy capacity is still far from the 6 GW (gigaWatt) goal set by the Dutch government. The control problems will most likely only become evident when the wind turbine capacity is a significant fraction of the total generating capacity. Therefore we have made our estimates on the magnitude of this effect on the basis of German data, where now about 23 GW is installed, and where extensive pertinent datasets have been published.

Germany.

In support of the government policy of support for sustainable energy, the country has chosen for large-scale application of wind energy. Achievements in this respect are regularly reported on[3].

The wind turbines are spread out over all of Germany, from Bavaria in the South to offshore in the German Bight in the North. Since the beginning of this century the amount of installed power has increased almost fourfold, from 6 GW in 2000 to 23 GW in 2008. The latter amounts to the equivalent of some 20 conventional power stations. The Germans have published on both the installed capacity and the actual annual electricity yield, as is shown in table 1. All data are from “Wind energy report 2008[3]”

Table 1.

Year	Power [MW]	Yield [TWh]	Wind turbine duty factor[4]
2000	6050	8,8	17%
2001	8680	10,9	14%
2002	11850	17	16%
2003	14500	19,2	15%
2004	16480	26,8	19%
2005	18290	27,1	17%
2006	20470	31,2	17%
2007	22090	40	21%

Table 1. The installed wind power in Germany and the actual yearly electricity production in TWh (terawatthour) and the derived wind turbine duty factor[4] (= ratio effective power / installed power).

Over the given years the wind turbine duty factor (defined as the ratio of what was delivered to the net and the amount that would have been delivered with design capacity of the wind turbines[4] was on average 17% or 17,5% (weighted average). When considering these figures one has to keep in mind that by law wind-generated electricity has absolute priority over all conventionally generated electricity. When wind generated electricity is available, it must be used. The output of other power stations has to be reduced commensurately.

The data in table 1 cover wind turbines all over the country, so the effect of wind variability over the country is taken into account. Firstly, we observe that the contribution of this large “name plate” (design) capacity is rather modest. Secondly, the effect of spreading the turbines over a large geographical area did not solve this problem. This does not just hold for Germany, as has been observed in a report to the British House of Lords[5]. But then, every sustainably generated unit of electricity counts, and this means a saving on fossil fuel use and a reduction of CO_2 emission, one would presume. Anyway, this was and is the reason to invest in wind turbines in the first place.

Wind and electricity

In the introduction we mentioned the issue of wind supply variability and the lack of an acceptable method for electricity buffer storage to cope with this variability. That variability is a huge issue as is demonstrated in the figure.

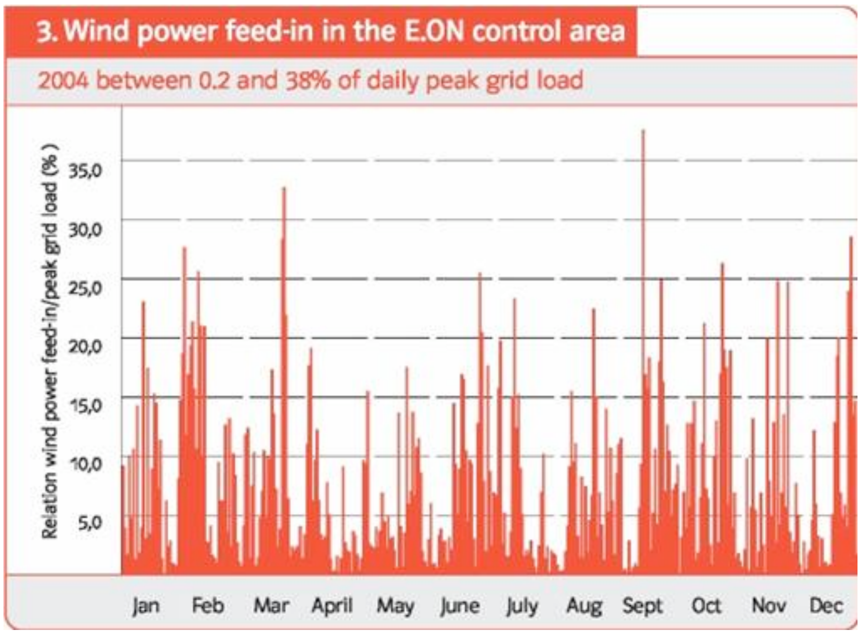


Figure. (E.ON Wind Report 2005) Fraction delivered by wind of the total delivered power. Wind delivery varied from 0,2% to 38% of total power delivered to the grid.

E.ON is the largest German wind-generated electricity provider. They demonstrate in the figure the significant engineering challenge they had to cope with over the time span of a year, as the fraction "wind" in the electricity they delivered varied from 0,2% of the total to as much as 38%. In the year this figure relates to, E.ON had as much wind power capacity as the Dutch government targets for the future. The strong variation in yield over time is partly the result of the given unfavourable physics of wind energy: the energy yield varies with the 3rd power of the wind velocity. In practice: when the wind blows at half the wind turbine design speed, the electricity yield is only one eighth of the design output, some 12% of the design capacity. Furthermore, there are days when there is no wind at all over almost the whole geographical area. In both cases, a very significant amount of energy must come from the conventional sources.

The effect of giving sustainably generated electricity priority in

Germany has the following obvious consequences: when the wind turbines operate at design capacity, up to 23 GW is produced. When there is little or no wind, up to 23 GW of electricity must be largely or fully provided from non-sustainable sources. In the German practice this means that now up to 23 GW must be in stand-by mode. Prof. Alt from the Technische Fach Hochschule Aachen[6] has concluded that this is indeed the practice, even when the German Wind Energy Report[3] states that this standby power is only 90%. It is obvious that there is an extra capital charge involved in

- Maintaining this back-up power, and
- Making the additional investments in the high tension network and
- Coping with the wind fluctuations.

However, we will not discuss these economic aspects here.

Estimating the adverse effect of the wind-induced inefficiency of conventional power stations.

We want to focus on the effect of the wind-induced extra variability on the efficiency and thus the power use of conventional power plants. So far, we have been unable to find data on this additional fuel use. If these data are gathered, they have not been published. The conventional power stations, meanwhile, do what they have been asked and provide the supply security that wind cannot provide. In view of the lack of data on this effect, we have gone out on a limb and made some estimates on the effect of wind variability on fuel efficiency of the back-up power stations. We hope to connect with the experts that have the real data or who can significantly improve on our estimates. We must make the following assumptions for our estimate:

1. The installed wind capacity operates several times a year at design capacity. It follows that the back-up units must provide this capacity when there is no wind. This assumption is supported by the observation of Prof. Alt, that after installing the wind turbines in Germany (and Denmark) no conventional power station has been decommissioned. As we mentioned in the previous chapter, he also believes that the full 100% back-up power (“Spinning reserve”) is required.
2. Only a fraction of the back-up power stations are open cycle gas turbines. By careful planning part of the stochastic wind supply variations can be balanced by ramping up or down of large-scale efficient conventional plants. Only the most rapid and or unexpected unbalances are taken up by switching gas turbines on or off. (We remind the reader that extra balancing effort even when planned always means extra wear and fuel

use for the large power stations).
3. The electrical efficiency of a modern conventional power station is set at 55%, and that of an open cycle turbine at 30%.
4. We know that 1 kWh of electrical energy requires 270 grams of hard coal[3], so that 1 kWh wind generated power saves 270 gram hard coal, excluding the effect of back-up inefficiency.

We now consider the production of 100 kWh electricity for which wind turbines have been built. After a year it turns out that on average 17,5 kWh have been supplied by wind, and the rest from conventional power plants, effectively serving as back-up. Assuming that these conventional plants delivered under optimum conditions, this required 82,5 x 270 = 22 275 g of hard coal, and 17,5 x 270 = 4 725 g of coal is saved producing this 100kWh.

However, the wind generated production has priority and forces the conventional stations to reactively ramp up and down. In the extreme case of the use of rapidly reacting open-cycle gasturbines only to achieve this, the efficiency falls from 55% to 30%.

Table 2 shows how the decreasing efficiency influences the saving of conventional fuel. At an overall efficiency rate for the back-up system of 45% the fuel saving already becomes negative and there is an extra fossil fuel demand. Wind electricity generation in this case produces extra CO_2, which is a truly counter intuitive result. If this level of inefficiency is truly the result of wind energy use, a cynic could observe that Putin and OPEC might want to promote wind energy in countries like Germany in order to increase its dependency on fossil fuel.

Please note that the reduced efficiency only applies to the back-up power stations. The other conventional stations operate at their regular efficiency.

Table 2.

Efficiency conv.station	**Consumption [g coal]**	**Extra consumption**	**Ultimate saving [g coal]**	**Visible efficiency**
55%	22275	0	4725	55%
53%	23116	841	3884	54%
51%	24022	1747	2978	53%
49%	25003	2728	1997	52%
47%	26066	3791	934	51%
45%	27225	4950	-225	50%
43%	28491	6216	-1491	49%
41%	29881	7606	-2881	48%
39%	31413	9138	-4413	48%

37%	33111	10836	-6111	47%
35%	35004	12729	-8004	46%
33%	37125	14850	-10125	45%
31%	39520	17245	-12520	44%
29%	42246	19971	-15246	43%
27%	45375	23100	-18375	42%
25%	49005	26730	-22005	41%

Table 2. The primary fuel saving (column 4) at assumed reduced efficiencies due to wind variation (column 1) and overall decrease in efficiency of all conventional power stations taken together (column 5). (100 kWh).

In Germany about 9% of the total electricity consumed is provided by wind. If the turbines were to work at design capacity, this would yield (100/17,5) x 9% = 51,4 % of the electricity demand. Therefore only 48,6% of the electricity can be conventionally produced under optimum conditions with say 55% efficiency. The remainder of the produced electricity, being 100-9-48,6%= 42,4% would be generated in a non-optimal manner.

Thus, at lower efficiencies, according to the list of table 2, the overall, visible efficiency of all conventional stations together is

{42,4 x (reduced efficiency) + 48,6 x 55}/91%

This result is shown in the last column of table 2. A reduction of overall efficiency say from 55 to 50% does not appear dramatic. But it does mean that the total wind turbine and auxiliary investment is useless in the sense that no emission reduction or fossil fuel saving has been achieved. This fact, that the investment in the hardware has meant a significant amount of extra fossil energy that will never be recuperated, aggravates the situation.

One can question whether a reduction in conventional generating efficiency by wind turbine involvement has been noticed at all, because this reduction is spread out in a random manner over the many providers and types of power stations.

We like to stress again that our estimate is only concerned with the operational phase of wind turbines. Extra energy and labour costs resulting from the need to have 90 to 100% back-up and the energy and expense required for bringing wind electricity to and on the high tension network have not been considered.

The back-up issue will with high certainty remain below the radar in the Netherlands for as long as the amount of wind power is modest. It certainly has not yet been noticed by the environmental movement nor the Dutch environmental minister Jacqueline Cramer or minister of Economic affairs Maria Van Der Hoeven.

Finally

We disregarded the economic aspects of wind turbine generated electricity. However, if it turns out that large-scale use of wind turbines only adds fossil fuel use and CO_2 emission, every Euro spent goes to waste. If however the back-up efficiency is such that some fuel and CO_2 emission is avoided, then a hard economic assessment is called for. We therefore refer to a very recent study" Economic impacts from the promotion of renewable energies[8]". This study concludes that from an economic point of view the use of wind and solar energy production is an enormous waste of resources.

Conclusions:

1. It is necessary to establish on the basis of data, rather than model predictions, the level of extra fuel use caused by decreased efficiency of fossil back-up for wind power, before countries translate large investment plans in wind energy into reality.
2. Wind energy easily costs more than it yields, not only in monetary terms, but also in non-sustainable energy use. Thus it will easily increase rather than decrease CO_2 emission.
3. Electricity companies must urgently provide the real data on extra fuel required to back up for wind-powered generators.

References & footnotes.

1. B.C. Ummels: Power System Operation with Large-Scale Wind Power…, Diss. TU Delft, februari 2009.
2. G. Dijkema, Z. Lukszo, A. Verkooijen, L. de Vries & M. Weijnen: De regelbaarheid van elektriciteitscentrales. Een quickscan in opdracht van het Ministerie van Economische Zaken, TU Delft, 20 april 2009.
3. Windenergy Report Germany 2008, ISET , Univ Kassel, Deutschland.
4. We use 'duty factor' in stead of 'efficiency of wind turbines', because we focuss in this paper on the efficiency of the spinning and standing back-up reserve of conventional power generation.
5. Brits Hogerhuis, Select Committee on Economic Affairs, Report 'The Economics of Renewable Energy, 2007-08': *"...The wider the area of interconnectedness, the more likely it is that variations in wind patterns will cancel out, although the weather may sometimes be similar over even a wider area. For example, we received some evidence that low wind speeds in the UK could coincide with similar conditions in Germany, Ireland and even as far away as Spain."*
6. H. Alt: Hardhoehengespraeche Siegsburg 30 sep 2009
7. Even that is not completely correct. Part of the wind produced electricity is

surplus to demand. Professor Alt describes what happens in Germany. The surplus wind electricity is exported for free and high fines are levied. The bill goes to the tax payer.

8. M. Frondel, N. Ritter & C. Vance: Economic impacts from the promotion of renewable energies: The German experience; Rheinisch-Westfälisches Inst. f. Wissenschaftsforschung, October 2009. http://www.instituteforenergyresearch.org/germany/Germany_Study_-_FINAL.pdf