The Real Cost of Wind Electricity

By Norman Rogers, 28 July 2015

This article is a technical exposition on how to calculate the cost of generating wind electricity. The goal is to show the true cost of wind electricity compared to conventional sources of electricity. Wind is important because it is the lowest cost type of renewable electricity that is also scalable. Some types of renewable electricity may be cheaper but have limited scaling possibilities because they depend special circumstances such as underground steam or favorable hydro sites.

Various agencies and think tanks calculate the cost of generating electricity. The U.S. government Energy Information Agency (EIA) is prominent. The EIA is biased against coal electricity and biased in favor of wind electricity. They, for example, increase the interest rates used for coal plants by nearly 30%.

Usually the cost of electricity is computed by taking the yearly capital cost of the plant amortized over the life of the plant and the annual operating costs. This yearly cost is divided by the number of kilowatt or megawatt hours produced per year to determine a cost per unit of electricity. The electricity is taken as the amount of electricity exiting at the plant fence.

This approach is fatally flawed in the case of wind electricity that is non dispatchable. Non dispatchable means that the grid managers cannot order wind to turn on when needed. Wind can be turned off, but then the power that would have been generated is lost. Rather than ordering wind to turn on or off, the grid is assumed to accept all the wind electricity available and adjust the other generators in the grid to maintain balance between supply and demand. Wind has to be operated this way in order to be remotely competitive. The grid has to supply a backup source of electricity to take over according to the vagaries of the wind. The worst case is no wind, so the backup has to be able to take over 100% of the wind.

The backup for the wind electricity is normally going to be gas turbines. Plants other than single stage turbines operating at less than full output so as to be able to ramp output up or down rapidly may also provide backup. Hydro electricity is a potential backup. Norwegian hydro is used to backup Danish wind.

Conventional power plants also require backup, but the backup requirements are far less than 100%. Normally the back up is sufficient to take over for one or two of the many plants connected to the grid at one time.

A complete grid, capable of providing reliable service, has considerable generating capacity that is little utilized because it only comes into play at peak load times and often only at seasonal peaks. If you add wind power to such a grid, the existing generating capacity can be used to backup the wind power. But, you have to ask, what is the point in adding wind power to the grid? Some generators will be put on standby because wind is carrying part of the load. That will save fuel. *But more money will be spent generating wind power than the cost of the fuel saved. Introducing wind increases the cost of power. Generating wind power costs between 5 and 12 cents per KWh. The value* of the fuel saved is only 0.4 cents per KWh for nuclear. For gas or coal the value of the fuel is 2 to 3 cents per KWh.

Wind power does not displace any capital investment in the conventional grid. The entire conventional grid infrastructure must be maintained because sometimes the wind generates nothing. Adding wind displaces fuel costing less than 3 cents per KWh with wind power costing 5 to 12 cents per KWh.

If you believe in catastrophic global warming, then you can assign an arbitrary number to the value of the CO2 not emitted. That allows one to justify any price for renewable, non CO2-emitting electricity. Since there is no way to calculate the number accurately and since global warming has apparently vanished for the last 18 years, we don't play that game here.

Sometimes it is proposed to backup wind power with electricity storage systems. There are various storage systems with limited capacity and high cost such as flywheels or batteries. But the only storage system with a large capacity at reasonable cost is pumped storage. That depends on two reservoirs at different heights and a reversible hydroelectric plant that can pump water from the lower reservoir to the upper reservoir to store electricity and run water through the turbine from the upper reservoir to the lower reservoir to generate electricity. Pumped storage depends on having a good site and still will usually be more expensive than fossil fuel powered backup. At least 10% of the energy stored is lost. If the wind dies for a long time there may not be enough capacity to keep generating electricity, depending on reservoir size.

The above argument should make it clear that it is not relevant to compare the cost of wind power at the plant fence with the cost of fossil fuel at the plant fence. You have to compare the cost of wind power with the marginal cost of fuel in the conventional grid. You can't permanently replace conventional power with wind power, because sometimes the wind is not blowing. Nevertheless it is instructive to make a comparison of costs.

The cost of electricity from a plant is calculated by dividing the annual cost of owning and operating the plant by the number of kilowatt hours of electricity generated in a year. The cost consists of the capital cost amortized over the life of the plant, fixed operating costs, and variable operating costs, mostly fuel. Be aware that the treatment here is simplified and power suppliers have to perform a more complicated analysis.

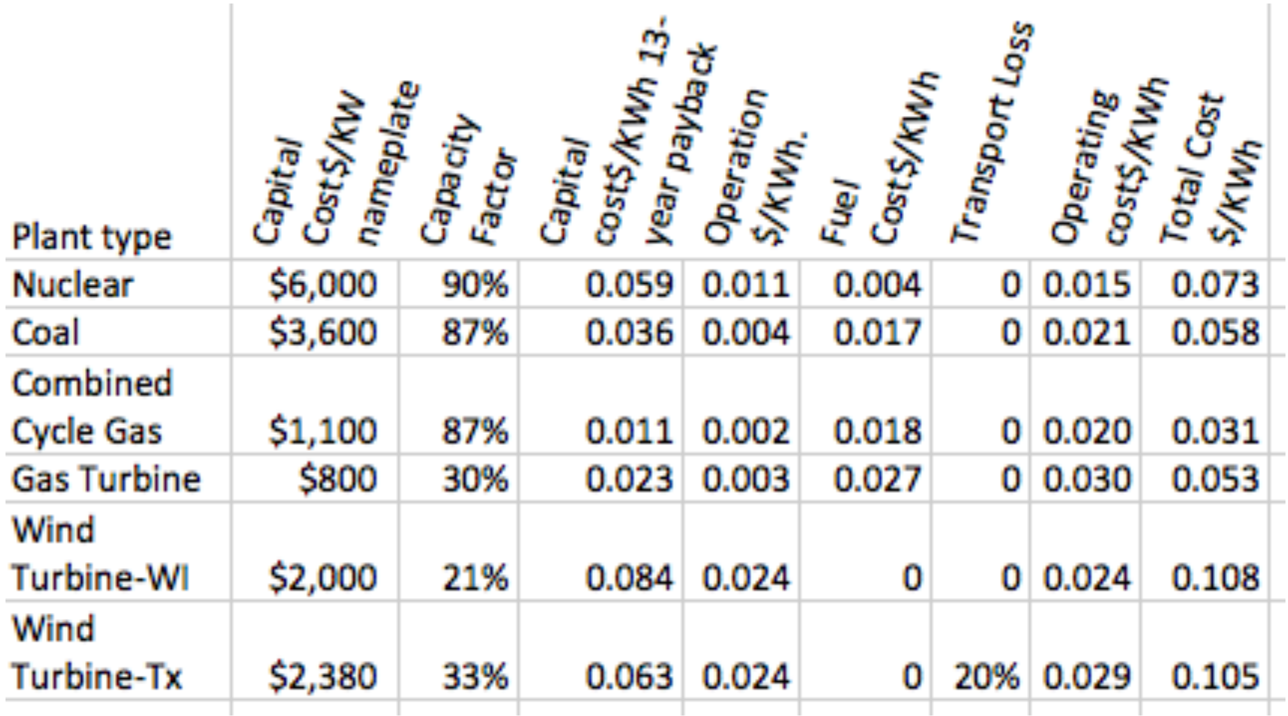
The EIA uses a 30 year amortization at 6.5% interest rate to compute the annual capital cost. This is similar to the annual payment on the 30-year mortgage at 6.5%. For coal the EIA uses a 9.5% interest rate. The annual cost can be computed using the PMT function in Excel. However to simplify the computation we assign an annual capital cost equal to 1/13th of the total cost of the plant. The result is the same as with the EIA method. The actual lifetime of wind turbines is probably less than 30 years,

perhaps as little as 15 years. Nuclear, coal and gas plants probably have practical lifetimes in excess of 30 years or even up to 60 years for nuclear plants.

Capacity factor is defined as the amount of electricity generated compared to what would be generated if the plant could operate at full output all the time. A low capacity factor increases the influence of capital costs because less electricity is produced for the same investment. New, efficient nuclear, gas or coal plants can operate with an 85% or 90% capacity factor. Gas turbines that only operate to handle peak loads may have a much lower capacity factor, say 30%. Wind power, in good circumstances, has a capacity factor of around 35%.

Consider the John W. Turk coal plant in the photo above. The operating cost and fuel cost is about 2.5 cents per kilowatt hour. The construction cost was $1.8 billion. To pay this back in 13 years requires a profit of $138 million per year. If the plant operates 85% of the time it will generate 4.47 billion kilowatt hours of electricity per year. [85% of 600 megawatts or 600,000 kilowatts, times 24 hours per day and 365 days per year.] To generate $138 million dollars profit per year, a profit of 3.1 cents per kilowatt hour is needed. Add this to the 2.5 cents operating and fuel cost and you have a cost of electricity of 5.6 cents per kilowatt hour.

In calculating the cost of wind electricity, the EIA uses a capacity factor in the range of 35% to 42%, the higher percentage corresponding to wind farms built in the future with an assumed improvement in technology. However, real wind capacity factors are available for two different grids, the *Western Interconnection* and the *Texas Grid*. The Western Interconnection includes the U.S. from Colorado west plus the two western provinces of Canada. The actual wind capacity factor for the most recent year available was 21%. For the Texas Grid, mainly covering Texas, for the most recent year, the wind capacity factor was 33%. The Texas Grid has the additional problem that the wind resources are in west and north Texas, far from the population centers where electricity is consumed. This necessitated a special power line increasing the capital cost of wind by 19%. In addition, about 20% of the power is lost in transportation of 500 miles from west to east. The following table is based on EIA figures and the Western Interconnection and Texas examples for wind. The EIA bias against coal has been removed and capital costs are computed on the basis of 1/13th of the total cost per year, equivalent to 30-year amortization at 6.5% interest.



Plant type	Capital Cost$/KW nameplate	Capacity Factor	Capital cost$/KWh 13-year payback	Operation $/KWh.	Fuel Cost$/KWh	Transport Loss	Operating cost$/KWh	Total Cost $/KWh
Nuclear	$6,000	90%	0.059	0.011	0.004	0	0.015	0.073
Coal	$3,600	87%	0.036	0.004	0.017	0	0.021	0.058
Combined Cycle Gas	$1,100	87%	0.011	0.002	0.018	0	0.020	0.031
Gas Turbine	$800	30%	0.023	0.003	0.027	0	0.030	0.053
Wind Turbine-WI	$2,000	21%	0.084	0.024	0	0	0.024	0.108
Wind Turbine-Tx	$2,380	33%	0.063	0.024	0	20%	0.029	0.105

The construction costs are in dollars per KW nameplate capacity and the electricity cost is in dollars per kWh of electricity produced. Combined cycle natural gas is least expensive at 3.1 cents per KWh. This is due to the low capital cost of about $1100 per kilowatt of capacity, the high capacity factor, realistic for new base load plants, and the low fuel cost for natural gas. Combined cycle plants use a gas turbine followed by a steam turbine driven by the exhaust heat from the gas turbine. This results in extracting near to 60% of the theoretical energy available in the fuel. Coal or single cycle gas does not go much over 40%.

Wind costs are 10.8 and 10.5 cents per KWh for the two examples. If the capacity factor for the Western Interconnection were 35% then the cost would be 7.4 cents per KWh, still more expensive than the other alternatives. If the 2.2 cent federal subsidy is factored in the cost of wind at 35% capacity factor would be 5.2 cents per KWh. But, as discussed previously, wind still would make no sense unless it cost less than the cost of fuel for the alternative. If the alternative is a single cycle gas turbine operating at 30% capacity factor and the federal subsidy is included, wind begins to look competitive. Obviously with a big enough subsidy and mandates forcing distribution utilities to buy renewable power at whatever price, wind becomes attractive. That is the reason a lot of wind power has been built. The billions spent on wind power is simply money wasted because in real economic terms it increases the cost of electricity.

There are additional costs imposed on the grid by wind, particularly if wind becomes a large part of the power capacity. When wind is running at near full capacity, the amount of power produced is 3 or 4 times the average amount produced by wind. If wind is 25% of the capacity, then when wind is running hot it might assume 75% of the load, requiring most of the remaining plants to be idled but ready to assume the load if the wind dies. Gas turbines and hydro may be compatible with these operational demands. Nuclear, coal and combined cycle plants are slow to change output and less suited to this scenario.

When making decisions regarding construction of new power plants the capital cost is important. But when presented with a system of existing plants, deciding which plants to operate, depends on the operating cost, ignoring the capital cost, a sunk cost. Although nuclear has the highest capital cost, it has the lowest operating cost because the fuel is very cheap. At the current time coal is the cheapest hydrocarbon fuel in terms of energy content, but due to the greater efficiency of combined cycle gas plants, natural gas is cheaper per KWh of electricity produced. Even though wind uses no fuel, the operating cost is higher than the fossil fuel alternatives because maintenance is expensive for the turbines.

It is likely that the cost of natural gas will increase in the future because the U.S. is expanding capability to export natural gas as liquified natural gas (LNG). Internal consumption of natural gas is increasing due to the low price, the result of fracking. On the other hand, coal is cheap, and will remain so for the foreseeable future.

Coal has a reliability advantage because a month or more supply of fuel is kept on hand at the power plant in the form of a pile of coal. Natural gas is supplied by pipeline and supply can be cut off or reduced by pipeline problems. Some gas plants have backup fuel in the form of tanks of oil that can also fire the turbines. However oil tanks are not always present and usually can’t provide as much backup as the coal pile.

Coal is transported by rail or water so plants must have a rail or water connection. Gas plants have to have a pipeline connection. Wind plants have to have good wind, often found in remote areas on hilltops, or on treeless plains.

Transmitting electric power involves losses of about 4% per 100 miles for a 345 kilovolt line and 1/4th that for a 765 KV line. For long lines of, for example, 1000 miles, direct current (DC) is used to avoid various problems, including losses due to radiation of power to space when the transmission line starts acting like a radio antenna. Lines with higher voltages or DC transmission cost more to build.

Sometimes wind and solar are touted by their supporters as the wave of the future, with technical progress constantly making them more competitive. There is plenty of reason to think that technical improvements and cost reductions in wind and solar will be modest. The technology is well understood and a lot of the cost is tied up in concrete and steel, the cost of which is stable.

On the other hand the real wave of the future is nuclear. There are many big possibilities for big improvements in nuclear that are technically well-understood and that are mostly an engineering challenge. For example, plants that burn nuclear waste, plants that are built in factories, plants that are intrinsically safe, etc.

Norman Rogers writes often about climate change and renewable power. His website is climateviews.com.

Notes:

Price of electricity different countries:
https://www.ovoenergy.com/guides/energy-guides/average-electricity-prices-kwh.html
https://www.energycouncil.com.au/analysis/worldwide-electricity-prices-how-does-australia-compare/

EIA estimates of cost of electricity from wind:

https://www.eia.gov/outlooks/archive/aeo14/pdf/electricity_generation_2014.pdf

Wind is given as $80.3 per megawatt hour or 8 cents per KWH. If the capacity factor changes from 35% to 21%, then the leveled capital cost increases from $64 to 64*35/21 or $107 and the cost per KWh increases by 4 cents to 12 cents.

Note: The EIA cost vary greatly from year to year. This is from the 2014 report for cost in 2019. The 2016 report forecasts more than a 30% reduction in capital cost for wind by 2022, due in part to an increase in the capacity factor from 35% to 42%. I find this to be implausible. The capacity factor can be increased by making the wind turbine larger or the associated generator smaller, in other words by increasing the capital cost per kilowatt hour. It is not likely that the capacity factor can be made larger at the same time the cost per KWh is decreased. Further, the best wind locations are taken first, so costs should be going up, not down. Wind turbines are a mature technology, so dramatic cost declines in 3 years are not to be expected. In any case, the capacity factor is wildly out of line with the 21% capacity factor actually experienced by the Western Interconnection.

The capacity factor for wind in the Western Interconnection: State of the Interconnection

https://www.wecc.biz/Reliability/2016%20SOTI%20Final.pdf

On page 20:

Wind nameplate capacity 22,800 megawatt hours.

If operating 100% this would result in 22800*24*365/1000=199728 gigawatt hours of electricity

Electricity actually generated=41,000 gigawatt hours.

Capacity factor=41000/199728= 20.52% ~21%

Capacity factor for the Texas Grid

Texas State of The Grid Report page 38
http://ercot.com/content/news/presentations/2016/2015_StateoftheGridReport.pdf

2015 energy use 347 billion KWh of which wind is 40,786,278 megawatt hours
Generation capacity 77,000 megawatt of which wind is 18% or 13,860 megawatts.
Capacity factor is 13860/40786= 33%

Cost of Power Lines for Wind Power on Texas Grid

https://www.dallasnews.com/business/energy/2013/04/05/west-texas-wind-power-transmission-project-nears-completion

$6.9 billion to carry 18,000 megawatts. 18,000 megawatts of wind turbines would cost $2 million per megawatt or $2 billion per 1,000 megawatts. The power lines cost 6.9/18= .38 billion per megawatt or .38/2= 19% extra cost for the lines for the wind power.

Cost of fuel for gas turbine generator:

1 KWh=3412 BTU.
If the turbine runs at 40% efficiency
1KWh=3412/.4=8530 BTU

Cost of natural gas $3.23 per 1 million BTU. (Varies)

KWh in 1,000,000 BTU = 1,000,000/8530=117 KWh

cost per KWh = 323/117=2.76 cents / KWh ~3 cents per KWh