

VerVent



Simple Comparison Tool Wind Turbines (SCTWT)

VerVent, April 2022

Introduction

VerVent is a small innovative engineering office that develops innovative sustainable solutions with a special focus on the offshore wind industry.

A core team of VerVent specialists is working on concept designs for a new powertrain for large-scale horizontal axis wind turbines (HAWTs) in the range 10-20MW+ and a vertical axis wind turbine (VAWT) with a split rotor. with counter-rotating top and bottom.

The concepts MergedGear and Megatorque 20 HAWT are the result of years of development. The first horizontal powertrain concept for wind turbines was conceptualized in 2013. This version of the Megatorque 20 (VerVent 1.0) already has the bevel gearbox as the main innovation.

For product development, VerVent wanted to know which technical and financial variables play a significant role for OEMs, the manufacturers of the components of the turbine, especially the nacelle.

Topics such as material use, type and quantity, transmission design, torque, wear, failure rates, efficiency, repair and maintenance, the differences between Direct Drive and Gearbox were all covered.

While much has been published, including recent literature on both Direct Drive and Gearbox turbines, it has not been possible to make a proper and reliable technical and financial comparison.

To get an idea of the differences between Direct Drive and Gearbox technology in terms of investment amount and cause of any differences, system losses, maintenance and repair share in the total annual costs, return and turnover, VerVent made a simple calculation model.

It is not a complicated and elaborate model (the name says it all: Simple). The model can provide sufficient information about the extent to which a particular variable influences the results and differences between turbines.

In addition, it is easy to change the input of the various parameters as better and more reliable information becomes available.

Of course, the model is used with the necessary basic knowledge of the user. Rubbish in = Rubbish out.

If the model calculations show that there are values on which further decision-making is possible, further work can be done on this.

VerVent has no right to wisdom. Do you have suggestions for improvements, or do you think based on your knowledge that a variable or formula needs to be adjusted? Let us know.

VerVent wishes you a useful and meaningful use of SCTWT and of course a lot of fun.

Starting Points

In the SCLWT it is possible to compare four wind turbines at the same time.

The efficiency of wind turbines depends on several variables. Obviously, the diameter of the blades and thus the energy that can be used for electricity production. In addition, the maximum power that can be used according to Betz (a theoretical maximum of energy that can be extracted from the wind by means of a rotor), the power coefficient (CP) and the wind speed.

The starting point for the turbines in the comparison is a reference wind speed (meters/sec), derived from the turbine table in figure, a Cp of 7 and an aerodynamic efficiency of figure 48 % (Betz table).

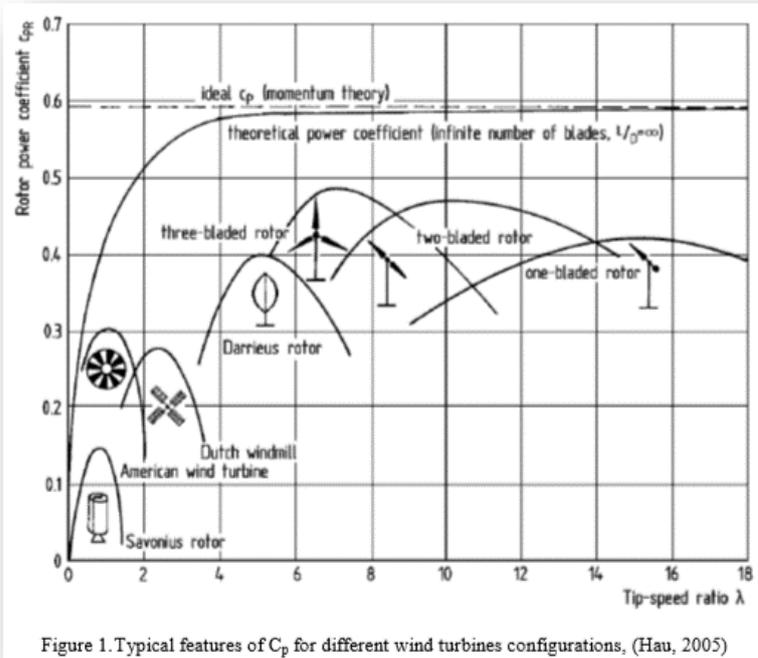
To do justice to the name of the model, Simple, of those three we only use the wind speed as a variable whose value can be adjusted.

Values to fill in

The yellow cells on the worksheet can be filled in and changed at will. On the right, next to these cells is a grey coloured framed example. If you want to go back to the original after using the model yourself, you can copy this frame and paste it into the same frame on the left.

Variables to be changed but remain the same for all four turbines are price per kWh, interest rate and operational period.

- Price Per kW produced
The kWh price is entered, which the producer receives for the electricity he supplies to the grid.
- Corporate Taxes
Corporate (income) tax is a tax levied on the profits of companies. In the Netherlands, the rates for corporate tax 2021 are 15 percent on the first € 245,000 of the profit and 25 percent on the rest. To keep the model simple, (only) a percentage can be entered. It does not matter much for the comparison.
- Operational period
The economic lifespan is used in the model. It is of course possible that the turbine or wind farm will run for even longer. Shorter is not desirable.



LCOE Comparison		Wind Turbines			November 2021	
Input						
<i>To calculate the LCOE of the turbine the following (yellow coloured) cells have to be filled in</i>						
Price Per kW produced	kWh	€ 0,065	Specific mass of air	1,225		
Corporate Taxes	%	25%	Betz factor	48		
Operational period	Years	20	Power coefficient (P)	7		
Wind Turbine	<i>type / oem</i>	AA 12 MW	BB 12 MW	CC 12 MW	EE 12 MW	
Power transmission	<i>DD of GB</i>	DD	DD	GB	GB	
Specified Rated Power	<i>MW</i>	12	12	12	12	
Diameter rotor incl. blades	<i>m¹</i>	220	220	220	220	
Gearbox Ratio	<i>n</i>	1	1	50	50	
Number of turbines in wind farm	<i>n</i>	70	70	70	70	
System losses	<i>% yield year</i>	11,00%	11,00%	14,00%	13,00%	
Opex (O&M & Other Costs per Year)	<i>% yield/year</i>	14,00%	13,00%	15,00%	14,00%	
Nominal Wind Speed	<i>m/sec</i>	11,0	11,0	11,0	11,0	
Capacity Factor	<i>%</i>	53,0%	53,0%	53,0%	53,0%	
Investment in one turbine		€ 35.000.000	€ 34.500.000	€ 33.250.000	€ 32.775.000	
Other Investments windfarm (structure, grid, etc.)		€ -	€ -	€ -	€ -	
Sum Investments	€	€ 2.450.000.000	€ 2.415.000.000	€ 2.327.500.000	€ 2.294.250.000	
Contribution of equity	%	20%	20%	20%	20%	
Cost of Debt	%	3,0%	3,0%	3,0%	3,0%	
Cost of Equity	%	10,0%	10,0%	10,0%	10,0%	

Variables that apply during the operational period can be changed individually for each turbine separately.

- Wind Turbine (OEM)
 - The user can fill in a name for a turbine given by the user himself, or the name of the Original Equipment Manufacturer (OEM), the type of turbine, and the power transmission (Direct Drive or Gearbox)
- Specified Rated Power in MW.
 - In principle, any value can be entered.
- Diameter rotor incl. Blades in m1
 - In principle, any value can be entered.
- Gearbox Ratio
 - The ratio of a Direct Drive Turbine is 1, for the gearbox, the corresponding ratio.
- Number of wind turbines

The model can calculate with a single turbine as well as with a wind farm. If it concerns a wind farm, the total amount of the investment can be entered at once, but also the amount of a single turbine multiplied by the number. The user then must make this sum himself.
- System losses
 - It is said that the system losses of Direct Drive differ from gearbox turbine. For a gearbox turbine 14% is more or less a standard. It is up to the user of the model to fill in the % he has experienced.
- Operating and maintenance costs
 - Also, the O&M costs of direct drive and gearbox turbines can differ. In the model these costs relate to the yearly yield. Fill in a percentage.

- If you believe, from your experience or other sources, that the financial outcome is too high or too low, you can change the percentage to the level that you believe is appropriate. It is also possible to adjust this percentage per turbine.
- Nominal Wind Speed
 - The wind is not equally strong everywhere during the year. Per turbine and/or wind farm it can differ per location and the effect on the yield is large. The wind speed that fits best in the chosen equation is entered.
- Capacity factor.
 - The capacity factor of a wind turbine is its average power output divided by its maximum power capability. In the case of a wind turbine, the maximum is the number of hours in a year, 8760 hours. So, a capacity factor of 50% is 4.380 full load hours.
- Investment
 - Enter the calculated investment costs for the wind energy object you need to build:
 - *Investment in one turbine.* A single wind turbine, costs for nacelle, rotor and blades, tower.
 - *Other investments in wind farm;* investments costs for the foundation, grid connection offshore wind farm to onshore hub
 - *Sum Investments.* You can sum up both investments (default) or fill in the total investments' costs at once.
 - It is up to the user how he wants to calculate the equation.
 - Stay alert:
 - Look at the sum. If you use then investment multiplied by the number of turbines and the cells with Other investments in windfarm, do not forget to make the sum complete.
 - You can also use other calculation methods. It is important that the total investment reflects the correct amount.
- Contribution of Equity
 - Fill in the percentage you bring in as equity
 - 10%, 25%, 90%
- Cost of debt
 - Fill in the percentage you must pay for the money you have lend
- Cost of Equity
 - Fill in the percentage you want to earn as a return of investment

Output

The most important outcomes are the LCOE and the turnover. These are situated directly after the input data.

Summary Results

From the data entered by the user, the main results are immediately visible, as well as a difference between the four wind turbines described. These results are:

Capex, the entire investment and divided into Equity and Debt, Opex (O&M & Other costs per year), Return (MWh), Turnover and LCOE (€/MWh).

The differences in % are based on the first turbine described. The difference is given for Capex, Opex, Yield and LCOE.

Results					
		AA 12 MW	BB 12 MW	CC 12 MW	EE 12 MW
Power transmission		DD	DD	GB	GB
Financial Calculations					
Debt		€ 1.960.000.000	€ 1.932.000.000	€ 1.862.000.000	€ 1.835.400.000
Equity		€ 490.000.000	€ 483.000.000	€ 465.500.000	€ 458.850.000
Ratio Debt Equity		4,00	4,00	4,00	4,00
WACC (nominal)		0,0380	0,0380	0,0380	0,0380
Annuity		15,13	15,13	15,13	15,13
Annuity Amount		€ 129.565.576	€ 127.714.640	€ 123.087.298	€ 121.328.908
Total Costs for loans Economic Life time		€ 631.311.528	€ 622.292.792	€ 599.745.952	€ 591.178.153
Power Calculations					
Rotational Speed Rotor (nominal)	<i>rpm</i>	6,68	6,68	6,68	6,68
Swept Area	<i>m²</i>	38.013	38.013	38.013	38.013
Power at reference wind speed	<i>kW(h)</i>	14.875	14.875	14.875	14.875
Rated GrossPower	<i>MW</i>	13,24	13,24	12,79	12,94
Power density	<i>W/m²</i>	348	348	337	340
Annual energy yield:	<i>MWh</i>	4.302.587	4.302.587	4.157.556	4.205.900
Torque at reference wind speed	<i>kNm</i>	18.914	18.914	18.277	18.489
Operational Results					
LCOE €/MWh		€ 51,64	€ 50,10	€ 52,01	€ 50,06
Annual energy yield:	<i>MWh</i>	4.302.587	4.302.587	4.157.556	4.205.900
Opex (O&M & Other Costs per Year)	<i>year</i>	€ 60.236.219	€ 55.933.632	€ 62.363.341	€ 58.882.596
Turnover	<i>year</i>	€ 279.668.159	€ 279.668.159	€ 270.241.142	€ 273.383.481
LCOE Sum per year	<i>year</i>	€ 222.193.189	€ 215.576.931	€ 216.222.463	€ 210.543.731
Gross Profit	<i>year</i>	€ 57.474.970	€ 64.091.228	€ 54.018.680	€ 62.839.751
Differences in %					
		AA 12 MW	BB 12 MW	CC 12 MW	EE 12 MW
Capex		100,0%	98,6%	95,0%	93,6%
Opex (O&M & Other Costs per Year)		100,0%	92,9%	103,5%	97,8%
Yield (MWh)		100,0%	100,0%	96,6%	97,8%
LCOE €/MWh		100,0%	97,0%	100,7%	96,9%

Overview of input and output of data

You can get a copy of the value of the results from the sheet if you copy and paste all the data into another worksheet.

These can be copied and placed elsewhere as values.

- Select the complete sheet from top to the end
- Command: Copy
- Open a new worksheet
 - Place the cursor where you want to paste the selected cells
- Command: Paste Special; tick: column width
Thereafter:
- Command: Paste

The sheet consists of the following parts.

Financial Calculations

- Debt
Result of the total investment (Capex) minus the contributed equity
- Equity
Result of the percentage contributed as equity, multiplied by the total required investment
- Ratio Debt Equity
Variable, needed to determine the annuity
- WACC (nominal)
Weighted average cost of capital (WACC) is used by analysts and investors to assess an investor's returns on an investment in a company. As most businesses run on borrowed funds, the cost of capital becomes an important parameter in assessing a firm's potential for net profitability. WACC measures a company's cost to borrow money, where the WACC formula uses both the company's debt and equity in its calculation.
- Annuity
An annuity is a series of payments made at equal intervals. Annuities can be classified by the frequency of payment (deposits). The amount of the annuity is determined by the term, the interest rate that must be paid on the capital raised and the equity-debt ratio.
- Annuity Amount
Debt divided by the annuity
- Total Costs for loans Economic Lifetime
The cost of all annual annuities (the term) minus the debt

Power Calculations

Based on the input data, important results are given such as the total area covered by the rotor (including blades), theoretical efficiency based on wind speed and this area, the torque generated on the rotor. In addition, the coupling losses and the annual yield are calculated. Results shown are:

- Rotational Speed Rotor (nominal)
The tip speed of the blades is the result of the wind speed (m/sec) used in the calculation and the power coefficient (Cp value). This power coefficient applies to a three-bladed turbine and can be seen as an axiom. A tip speed of 80 rotations per minute is considered optimal. See also the explanation on page 3.
- Swept Area
The surface area covered by the rotor (hub + blades)
- Power at reference wind speed
The wind speed per second (reference wind speed), the energy that can be extracted from the air (specific mass of air) and the surface area covered by the rotor (hub + blades, swept area) determine the amount of electricity that can be produced by the turbine, the power at reference wind speed.
- Rated Gross Power
Electricity (MWh) that can be produced by the wind turbine, minus the system losses of the turbine
- Power density
Rated Gross Power divided by Swept Area = Watt/m².
- Annual energy yield
Rated gross power, multiplied by the capacity factor (% * total hours year)
- Torque at reference wind speed
The wind energy, which is converted into a rotating force (torque) is calculated by dividing the Rated Gross Power by Rotor Speed and multiplying by the constant factor 9,55.

Operational Results

- LCOE €/MWh
The levelized cost of energy (LCOE), or levelized cost of electricity as described in "*Levelized Cost and Levelized Avoided Cost of New Generation Resources. The Annual Energy Outlook 2021*", is a measure of the average net present cost of electricity generation for a generating plant over its lifetime. It is used for investment planning and to compare different methods of electricity generation on a consistent basis. The LCOE "represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle" and is calculated as the ratio between all the discounted costs over the lifetime of an electricity generating plant divided by a discounted sum of the actual energy amounts delivered:
$$LCOE \text{ for } 1...25\text{-year operating life} = (\sum (n=1) CAPEX + \sum (n = 1...25) OPEX) / \sum (n = 1...25) AEP.$$
- Annual energy yield
Rated Gross Power multiplied by the capacity factor (%*total hours year)
- Opex, O&M & other costs per year

The Opex is a direct result of the entered O&M percentage, multiplied by the annual yield.

- Turnover
Price Per kW produced multiplied by the annual yield
- LCOE Sum per year
This amount is the LCOE €/MWh multiplied by the annual yield
- Gross Profit
Turnover minus LCOE Sum per year

Contact

VerVent is a subsidiary of Sustainable Business Investment BV and part of the not-for-profit company Stichting ATO.

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