Design of Wind Energy Systems

CARL VON OSSIETZKY universität OLDENBURG

ForWind Center for Wind Energy Research

CIP Tutorial 01
Hints for the selection of main parameters

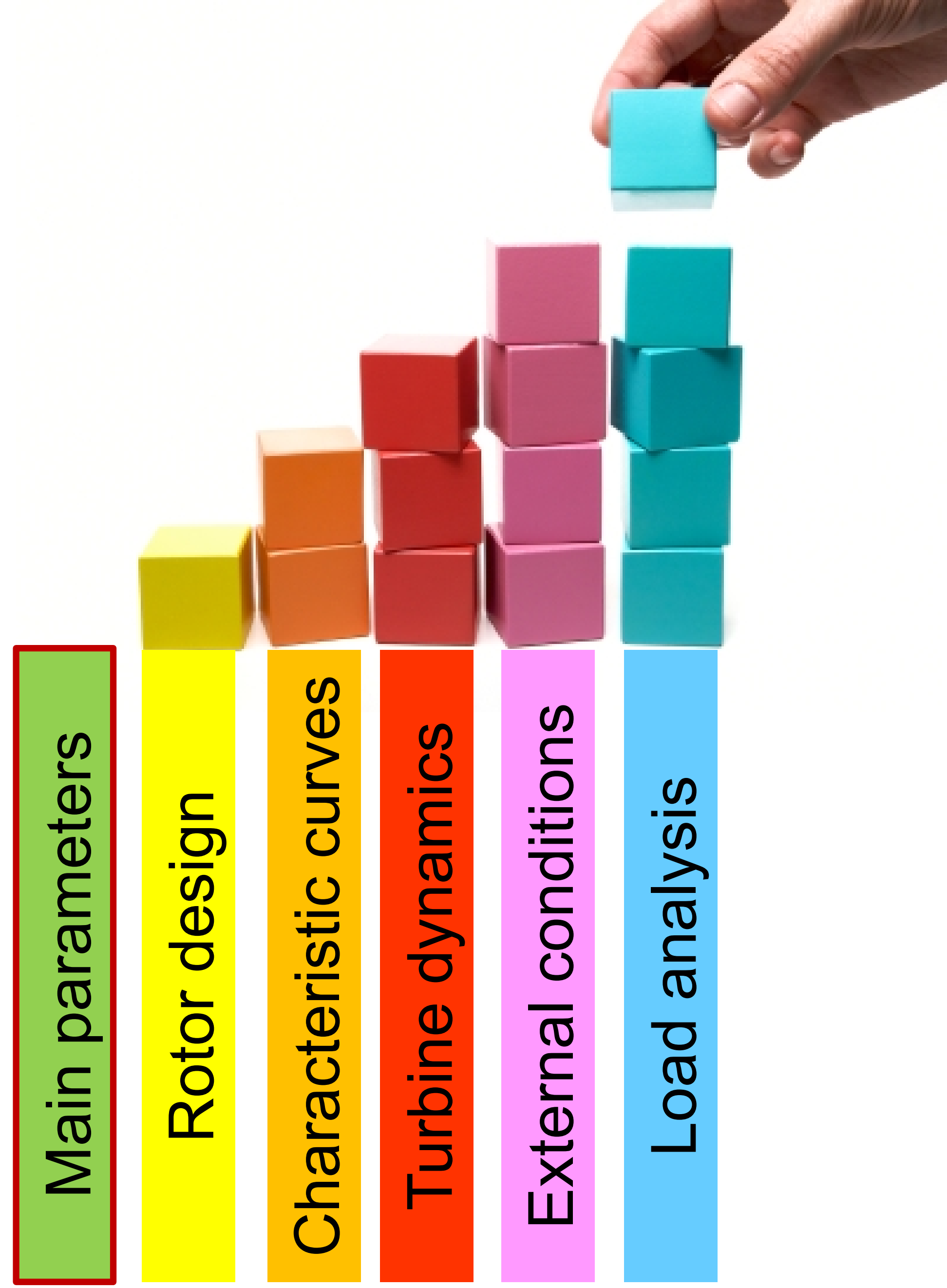
Prof. Dr. M. Kühn
Bernd Kuhnle, Luis Vera-Tudela

ForWind – Wind Energy Systems

Topics

- CIP tutorials & groups
- Review of supporting files
- Warm up – where do we start?
- Summary

CIP Tutorials



Groups

Nr.	Color	Student 1	Student 2	Student 3
1	Red	Mubdi Al-Masry		
2	Green	Alina Roß	Sonja Krüger	Laura Schröder
3	Blue	Teklehaimanot Aman		
4	Yellow	Paula Nardone	Alejandro Nitto	
5	Pink	Hossein Rezazadeh		
6	Turquoise	Stefan Arens		
7	Orange	Florian Börgel	Andreas Wöste	
8	Black	Darja Döhle	Jeroen Barnhoorn	David Schillebeeckx
9	Violett	Loma Al-Azzawi		
10	Grey	Arnd Fligg	Anja Külpmann	

Supporting files

1) Document with instructions
2) Table with airfoil data
3) Table with turbine data

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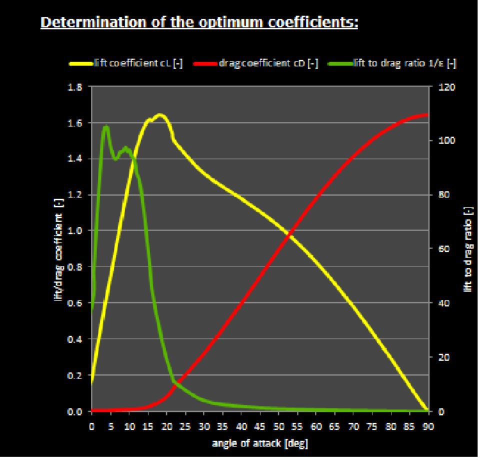
angle of attack α [deg]	coefficient c_L [-]	coefficient c_D [-]	coefficient c_M [-]	drag ratio 1/ε [-]
-180.0	0.000	0.010	0.000	0.000
-170.0	0.477	0.010	0.400	47.664
-160.0	0.953	0.096	-0.001	9.900
-150.0	0.922	0.322	0.102	2.863
-140.0	0.824	0.600	0.164	1.373
-130.0	0.718	0.898	0.224	0.800
-120.0	0.579	1.180	0.287	0.491
-110.0	0.404	1.414	0.350	0.286
-100.0	0.205	1.574	0.406	0.130
-90.0	0.000	1.641	0.450	0.000
-80.0	-0.205	1.574	0.466	-0.130
-70.0	-0.404	1.414	0.464	-0.286
-60.0	-0.579	1.180	0.449	-0.491
-50.0	-0.718	0.898	0.430	-0.800
-40.0	-0.824	0.600	0.424	-1.373
-30.0	-0.922	0.322	0.458	-2.863
-20.0	-0.941	0.124	0.544	-7.594
-10.0	-0.406	0.064	0.392	-6.304
0.0	0.186	0.005	0.042	39.198
0.5	0.245	0.005	0.043	51.384
1.0	0.304	0.005	0.043	63.507
1.5	0.363	0.005	0.044	74.213
2.0	0.422	0.005	0.045	85.172
2.5	0.480	0.005	0.045	93.894
3.0	0.538	0.005	0.046	102.438
3.5	0.594	0.006	0.046	104.894
4.0	0.649	0.006	0.046	104.951
4.5	0.702	0.007	0.046	101.416



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universität OLDENBURG ForWind

Institut für Physik

AG Windenergiesysteme (WE-Sys) • Prof. Dr. Dipl.-Ing. Martin Kühn

Design of Wind Energy Systems – Summer Semester 2015
Design-Tutorial 1: Selection of main parameters & rotor design

Prof. Dr. Martin Kühn

Bernd Kuhnle, Luis Vera-Tudela

Introduction

In tutorial 1 you have selected the most suitable wind turbine for given site conditions and related your choice to specific rating. In this design-tutorial you will estimate other main parameters that will help you to define a wind turbine model and will compare it to commercial turbines.

Additionally, you will calculate airfoil aerodynamic properties from tables and define the geometry of your blade, which will be used in following tutorials.

Section 1

Let's define the main parameters of your wind turbine and discuss some results.

1. Calculate total conversion efficiency (use Cp-reference, mechanical efficiency and electrical efficiency) and compare it to other technologies.
2. Using the total conversion efficiency, evaluate how much wind power has to be captured to obtain the nominal electrical power.
3. Estimate the rated wind speed and round it up. Use the reference max. blade length given.

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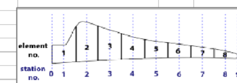
Data for group →	Unit	Black
Airfoil profile set number	-	4
Design wind regime	-	Rayleigh
Target wind regime	-	Medium
Weibull A-factor (local)	m/s	8
Weibull k-factor (local)	-	2.15
Rated electrical power	kW	3500
Number of blades	-	3
Cut-in wind speed	m/s	3.5
Cut-out wind speed	m/s	25
Max. tip speed	m/s	77
Max. hub height – reference (*)	m	115
Max. blade length - reference (*)	m	65
Blade root length	m	5.5
Transmission	-	116

General variables	Unit	Value
Air density	kg/m³	1.225
Steel density	kg/m³	8500
Steel E-modulus	N/m²	2.0000E+011
Gravity	kg/m²	9.81
Cp – Betz	-	0.5926
Cp – reference	-	0.5255
Mechanical efficiency	-	0.9455
Electrical efficiency	-	0.9469



Rotor configuration	Unit	Value
Hub vertical offset	m	3
Blade set angle	deg	0
Cone angle	deg	3
Tilt angle	deg	5
Overhang	m	6
Lateral offset	m	0
Hub diameter	m	2.5
Spinner drag coefficient	-	1

Main parameters	Unit	Value
Calculate total conversion efficiency (Cp_ref, mech_eff, elec_eff)	-	
Total wind power that needs to be extracted	kW	
Rated wind speed (rounded up)	m/s	
Rotor radius (rounded up)	m	
Blade length (without hub)	m	
Rotor area (rounded radius)	m²	
Specific rating (design)	W/m²	
λD Design tip speed ratio	-	
Rotor rated speed	rpm	
Blade element length (assume 8 elements of equal length)	m	

Blade aerodynamics	Unit	Value
Lift coefficient – Profile 1	-	
Lift coefficient – Profile 2	-	
Lift coefficient – Profile 3 (cylinder)	-	
Drag coefficient – Profile 1	-	
Drag coefficient – Profile 2	-	
Drag coefficient – Profile 3 (cylinder)	-	
Angle of attack – Profile 1	deg	
Angle of attack – Profile 2	deg	
Angle of attack – Profile 3 (cylinder)	deg	

Profile data	Unit	Value	Profile
Thickness to chord ratio	%		Profile 1
Reynolds Number	-		
Pitching Moment Center	%	0.25	
Deployment Angle	deg	0	
Including pitching Movement	-	Yes	
Thickness to chord ratio	%		Profile 2
Reynolds Number	-		
Pitching Moment Center	%	0.25	
Deployment Angle	deg	0	
Including pitching Movement	-	Yes	

Blade geometry		Description	Unit	Section number							
Theory calculation		Station number (not element)	-	0	1	2	3	4	5	6	7
		Distance (from rotor center)	m								
		Distance (from blade root)	m								
Betz theory	Profile 1	Chord length	m								
		Twist angle	deg								
	Profile 2	Chord length	m								
		Twist angle	deg								
	Check	Power per element	kW								
Schmitz theory	Profile 1	Chord length	m								
		Twist angle	deg								
	Profile 2	Chord length	m								
		Twist angle	deg								

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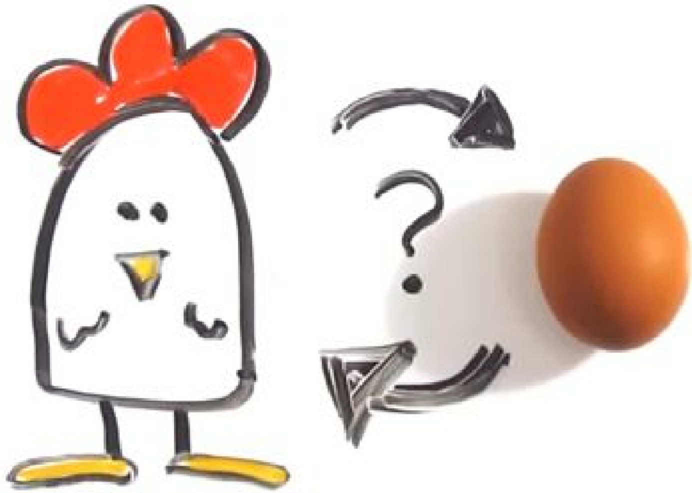
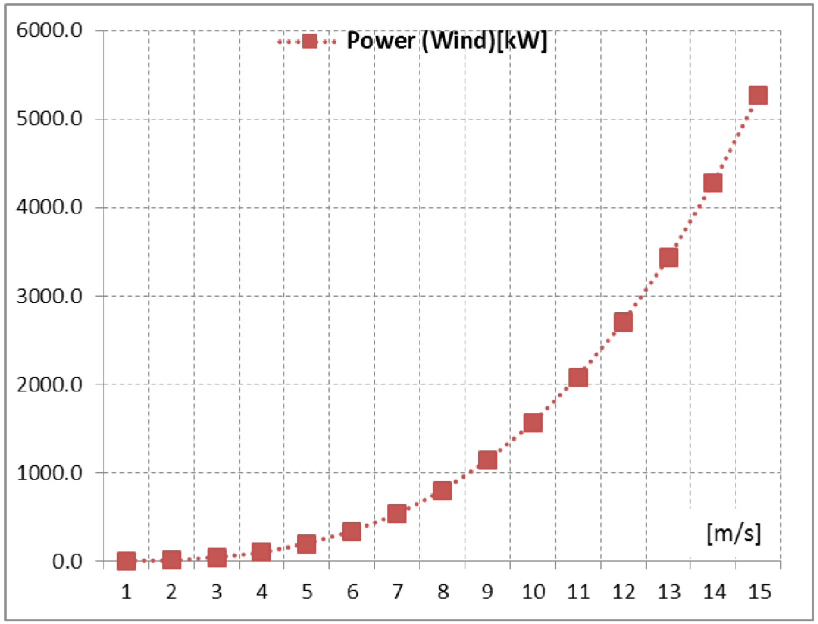
Warm up

- Where do we start?



Power

1. How is the power extracted from the wind calculated ?

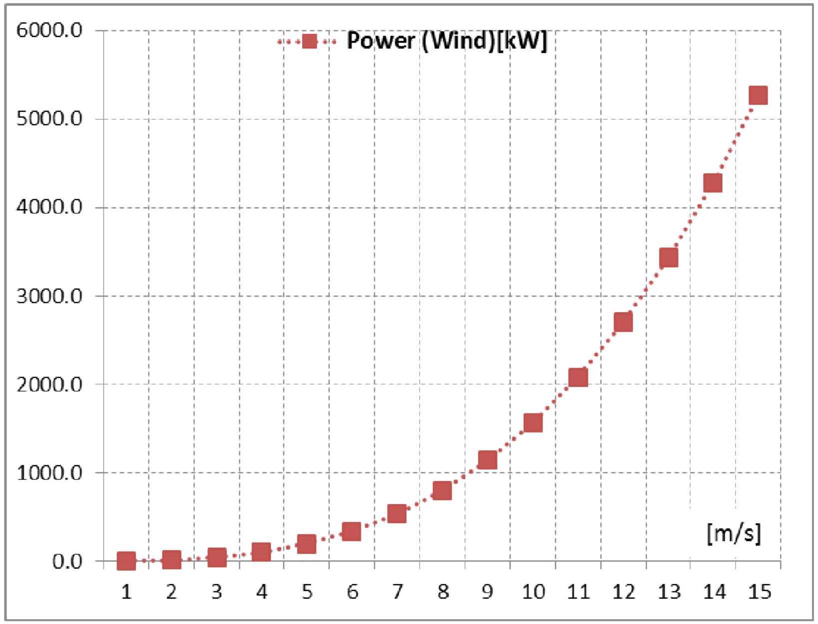


Power

1. How is the power extracted from the wind calculated?

$$P = \frac{1}{2} * C_p * \rho * \pi * R^2 * V^3$$

2. What ‚type' of power is it?
   a) Kinematic
   b) Aero-mechanical
   c) Mechanical
   d) Electrical



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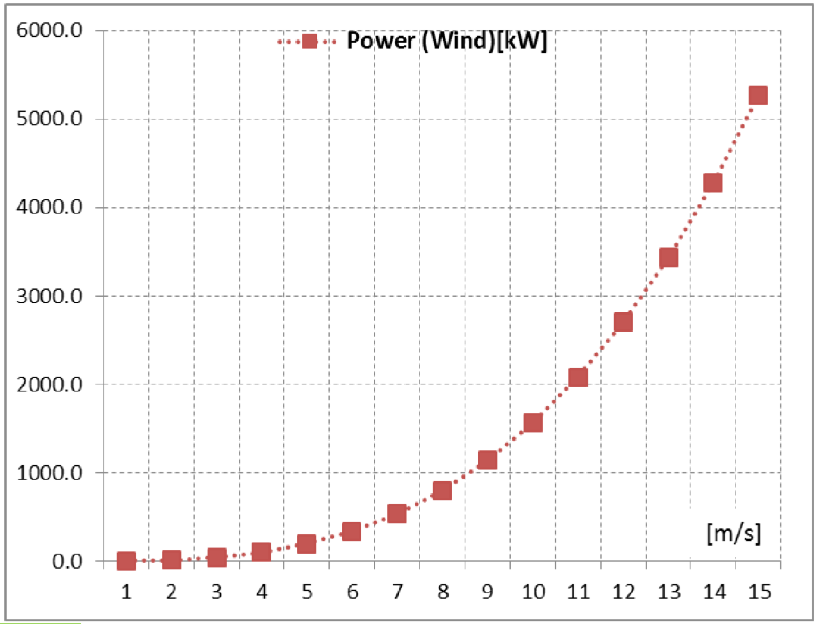

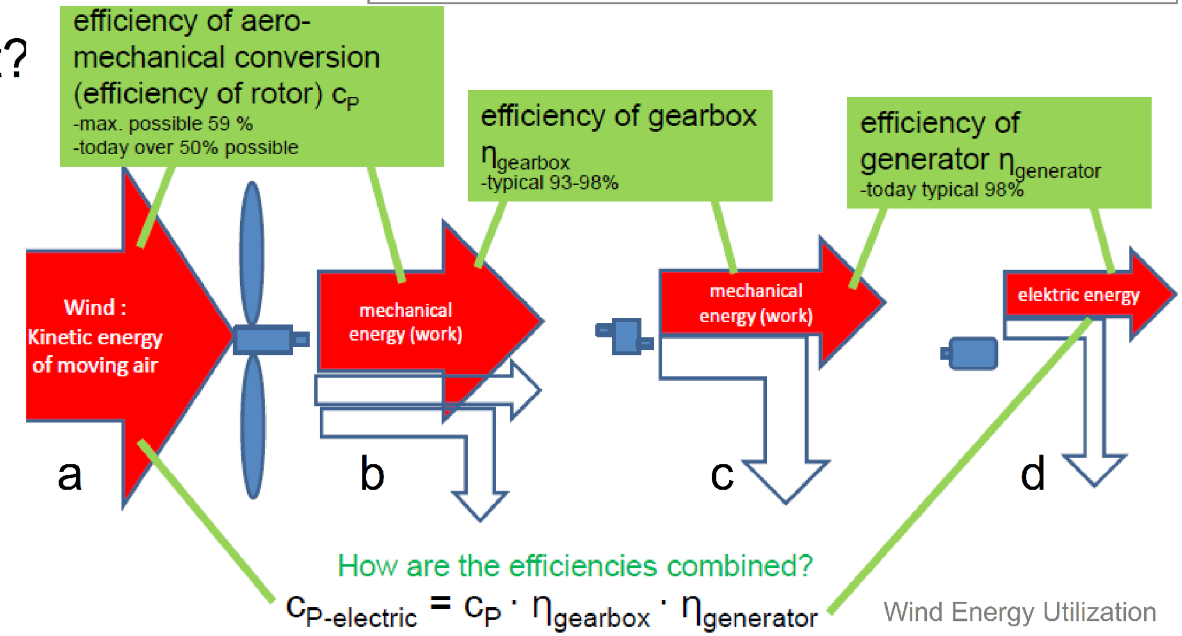

Wind Energy Utilization

Rated wind speed & blade length

1. How does the increase of rated wind speed affects the selection of blade length?

$$P_{aero} = \frac{1}{2} * C_{p-Betz} * \rho * \pi * R^2 * V^3$$

Air density [kg/m3]	1.225
Cp Betz [-]	0.59
Nominal power [kW]	1500
Nominal wind speed [m/s]	9

Note: example with P-aero

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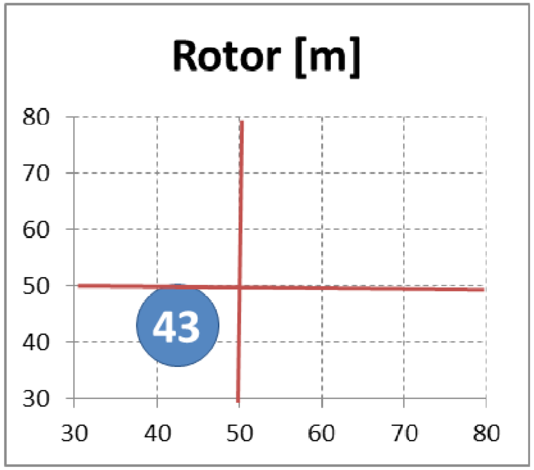

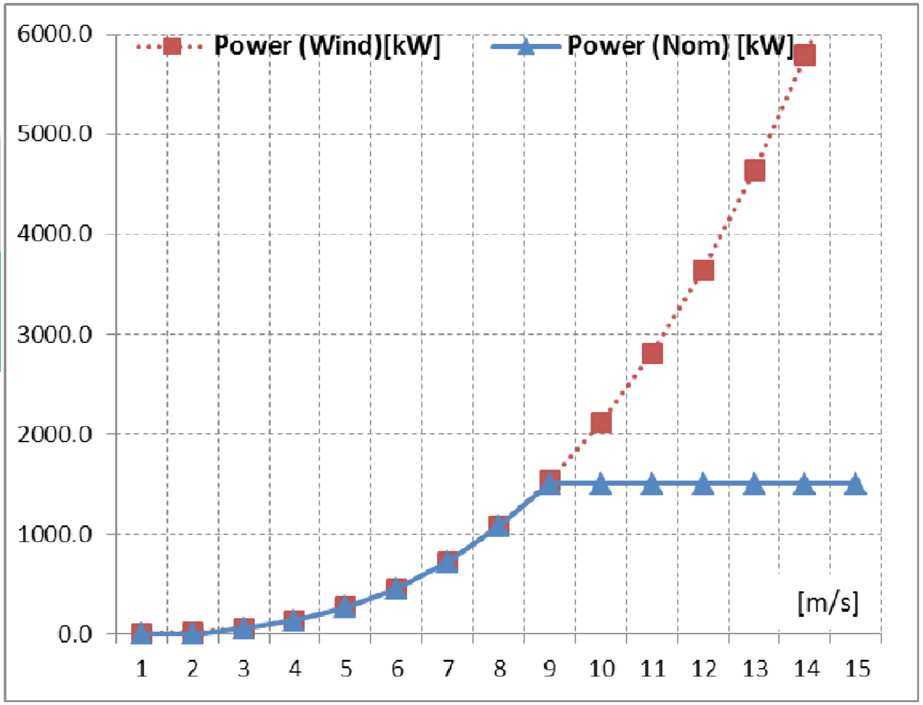

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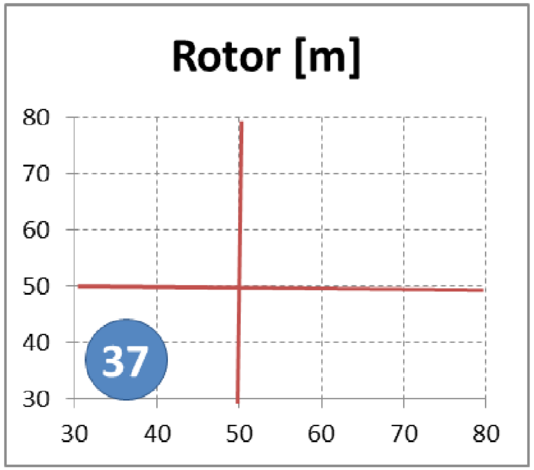
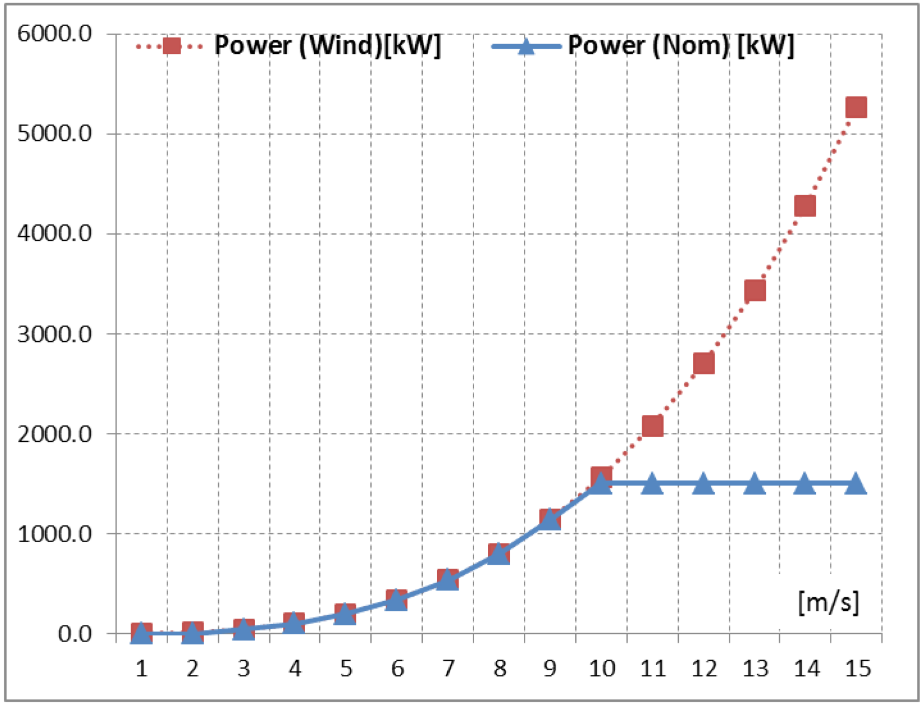
Note: example with P-aero





Rated wind speed & energy output

1. How does the increase of rated wind speed impacts output energy?

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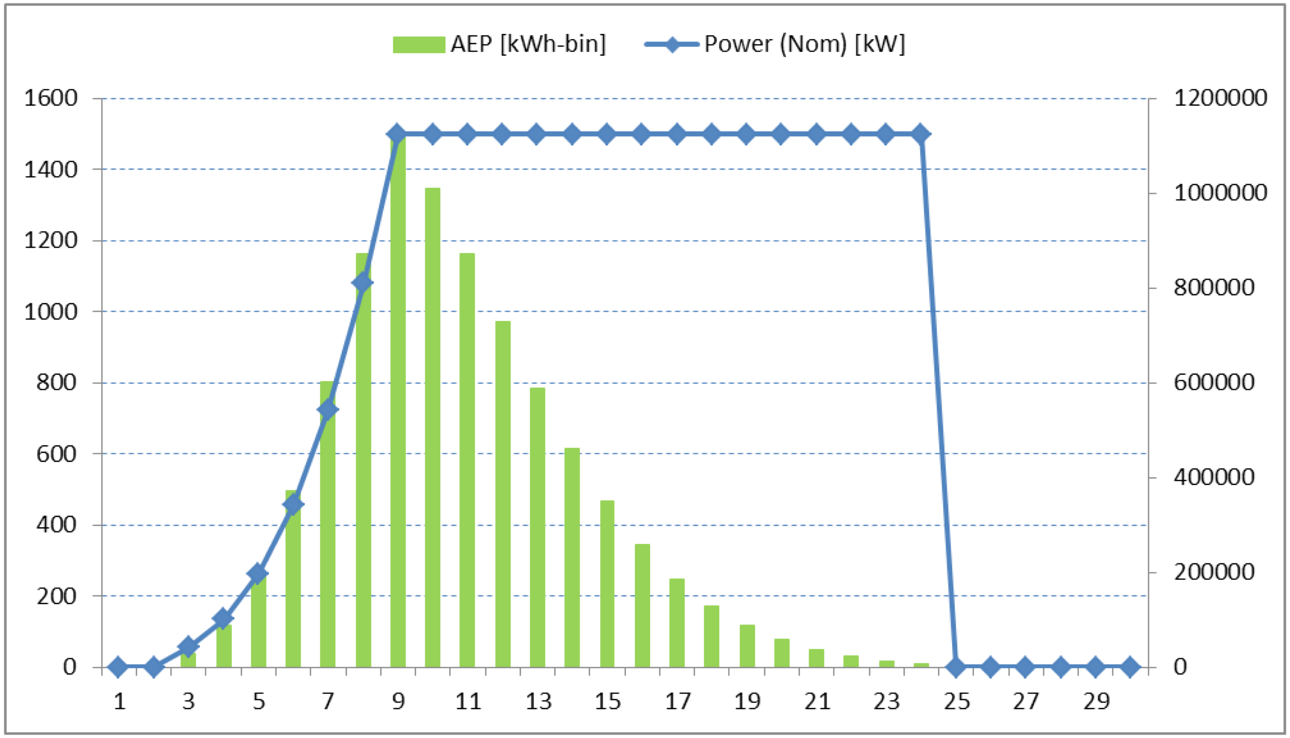
Cp Betz [-]	0.59
Nominal power [kW]	1500
Nominal wind speed [m/s]	9
AEP [MWh]	8114.66



Rated wind speed & energy output

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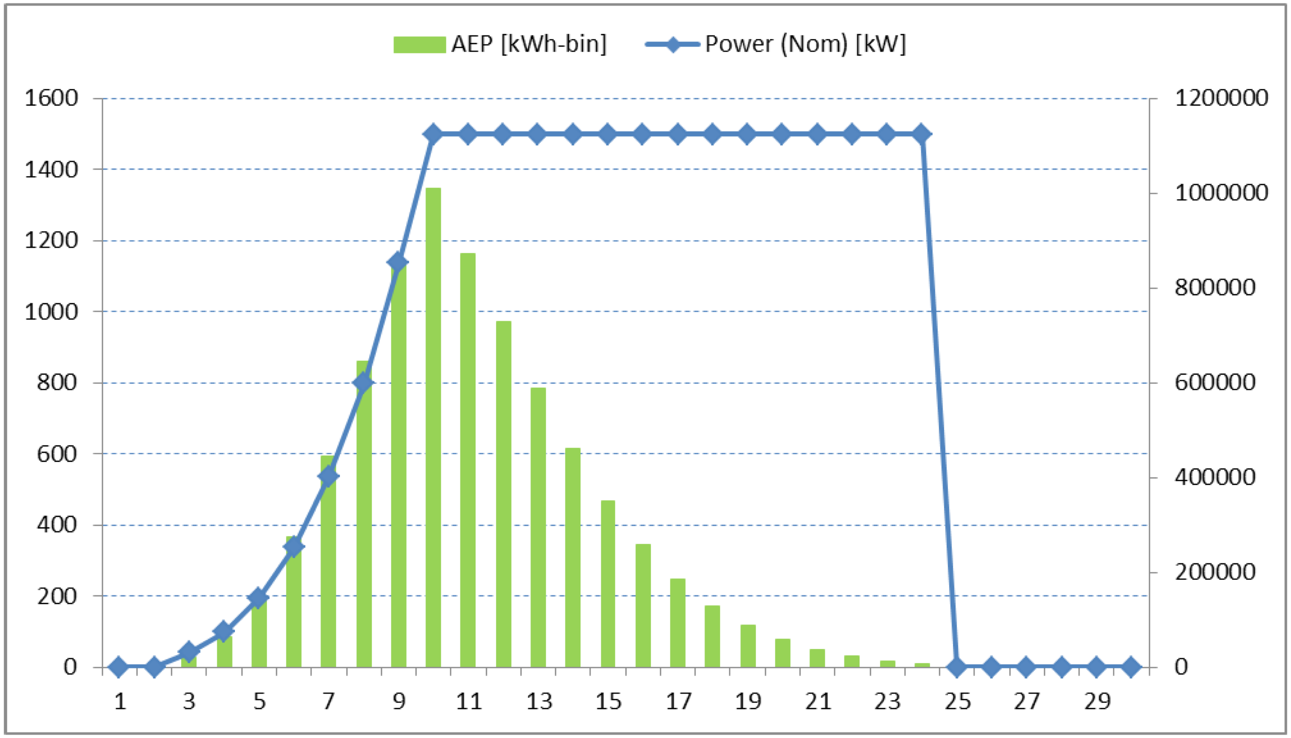
Air density [kg/m3]	1.225
Cp Betz [-]	0.59
Nominal power [kW]	1500
Nominal wind speed [m/s]	10
AEP [MWh]	7280.82



Wind turbine rating

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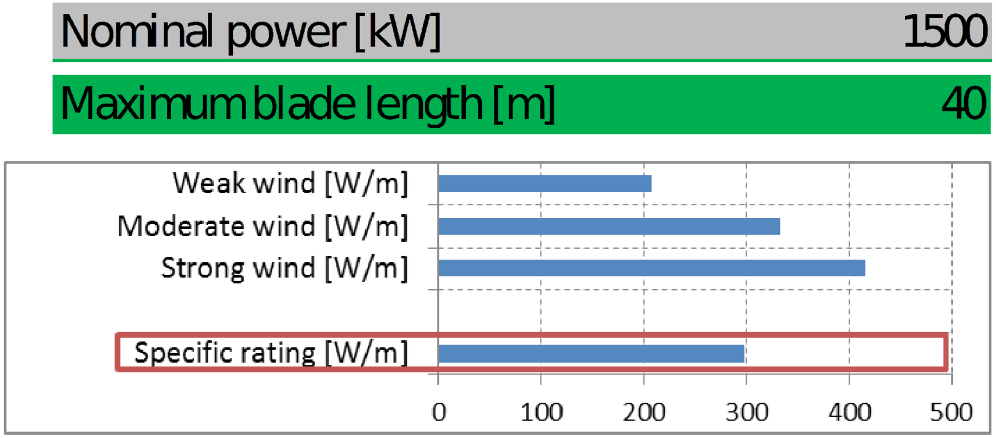
2. How does the rating of the wind turbine varies with the increase of the blade length?



Vera-Tudela's own analysis of few commercial wind turbines, 2014

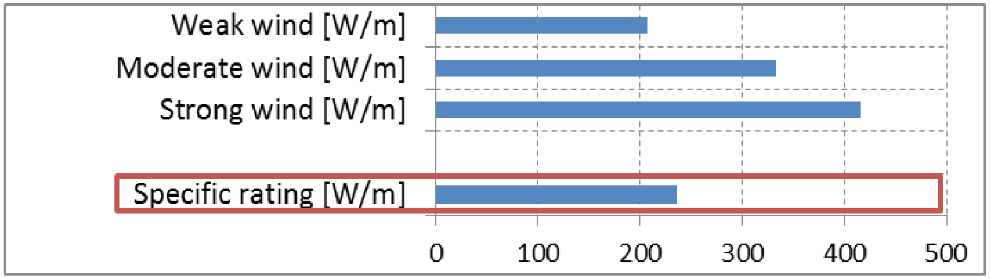
Wind turbine rating

1. What is the turbine rating?

$$rating\ [^{W}/_{m}] = \frac{electrical\ power}{area}$$

2. How does the rating of the wind turbine varies with the increase of the blade length?

Nominal power [kW]	1500
Maximum blade length [m]	45



Vera-Tudela's own analysis of few commercial wind turbines, 2014

Summary / Conclusion

- We went trough the list of CIPs and groups
- We reviewed the supporting files for this CIP
- We recall the relation between power, energy, rated wind, blade length and rating of wind turbines