Resource Potential: Wind Studies and Power Curves

Philip Bechtle

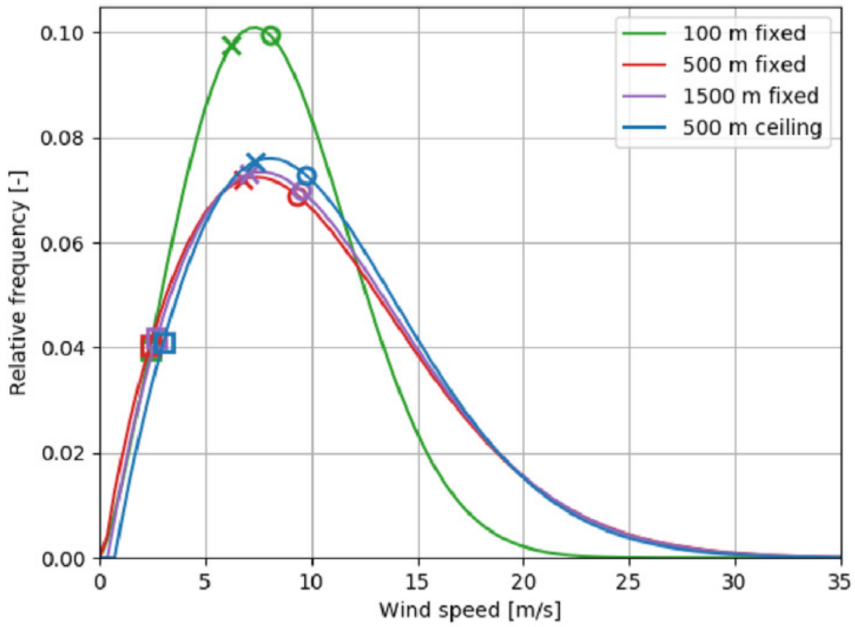
with a lot of inspiration and work from
Mark Schelbergen, Roland Schmehl, Elena Malz,
Rishikesh Joshi, Fiona Paulus, Max Rüger, Michelle Birr,
Udo Zillmann, Kristian Petrick

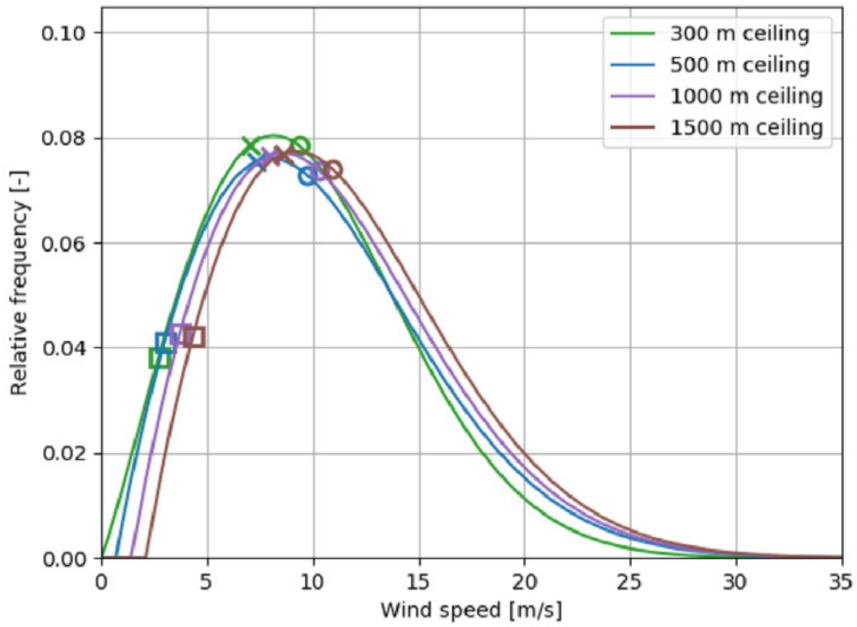
Physikalisches Institut

September 23rd 2020

universitätbonn

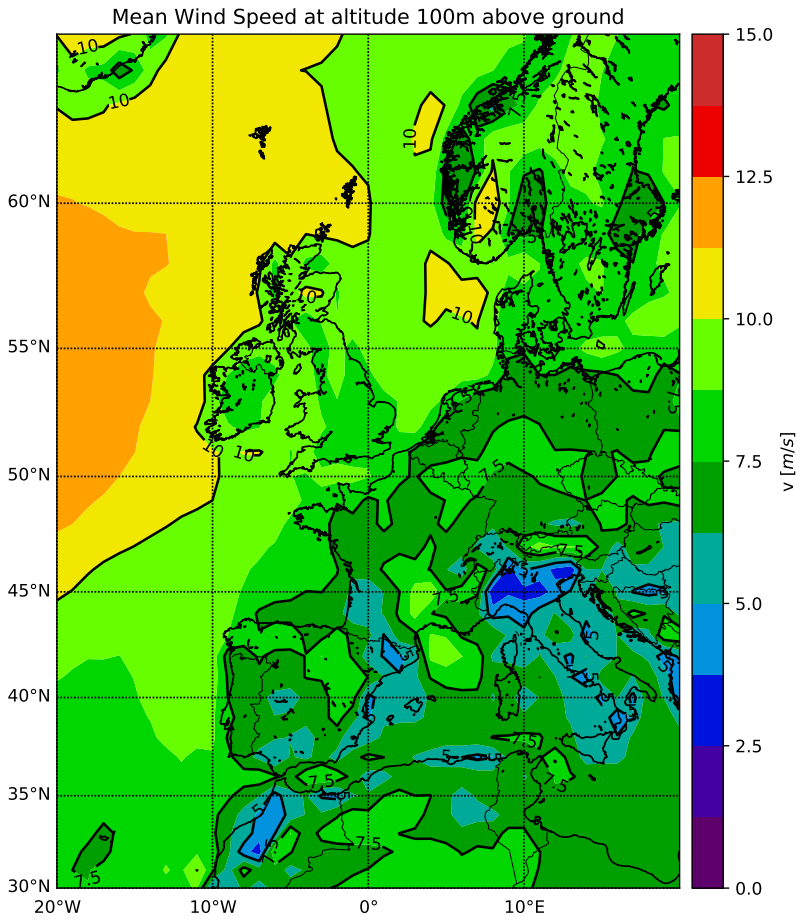
Integrating AWE Characteristics into the Source Potential



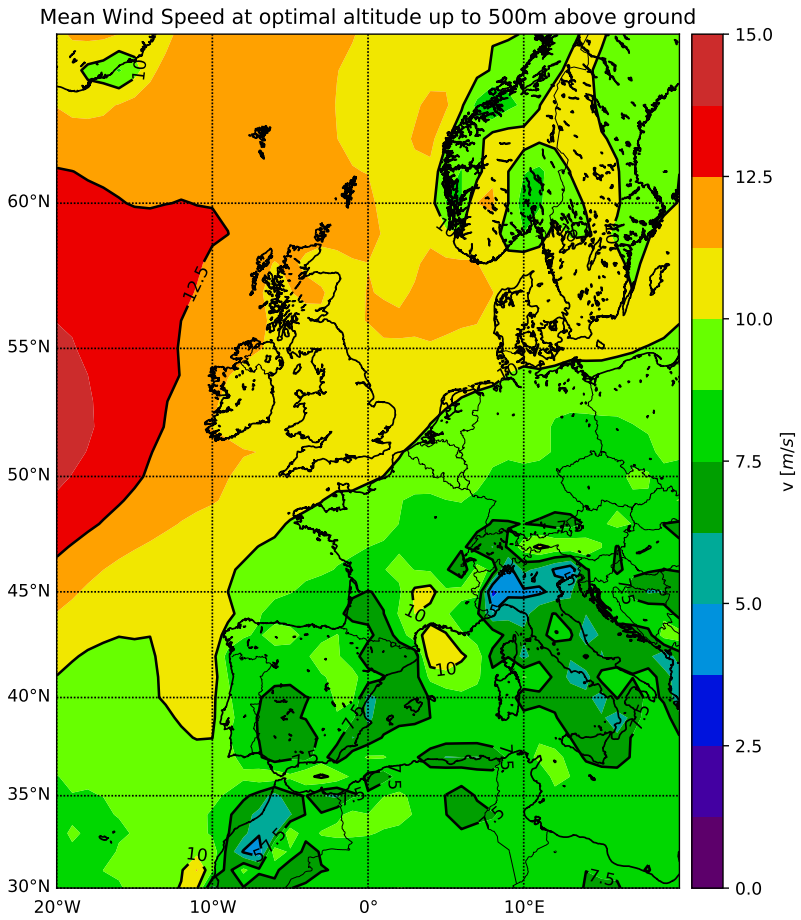


- For every location on a $1^\circ \times 1^\circ$ map, find the optimal wind speed below a given ceiling for every hour from 2010 to 2017
- Find dramatically improved wind at variable height compared to fixed altitudes

The Mean Wind Speed

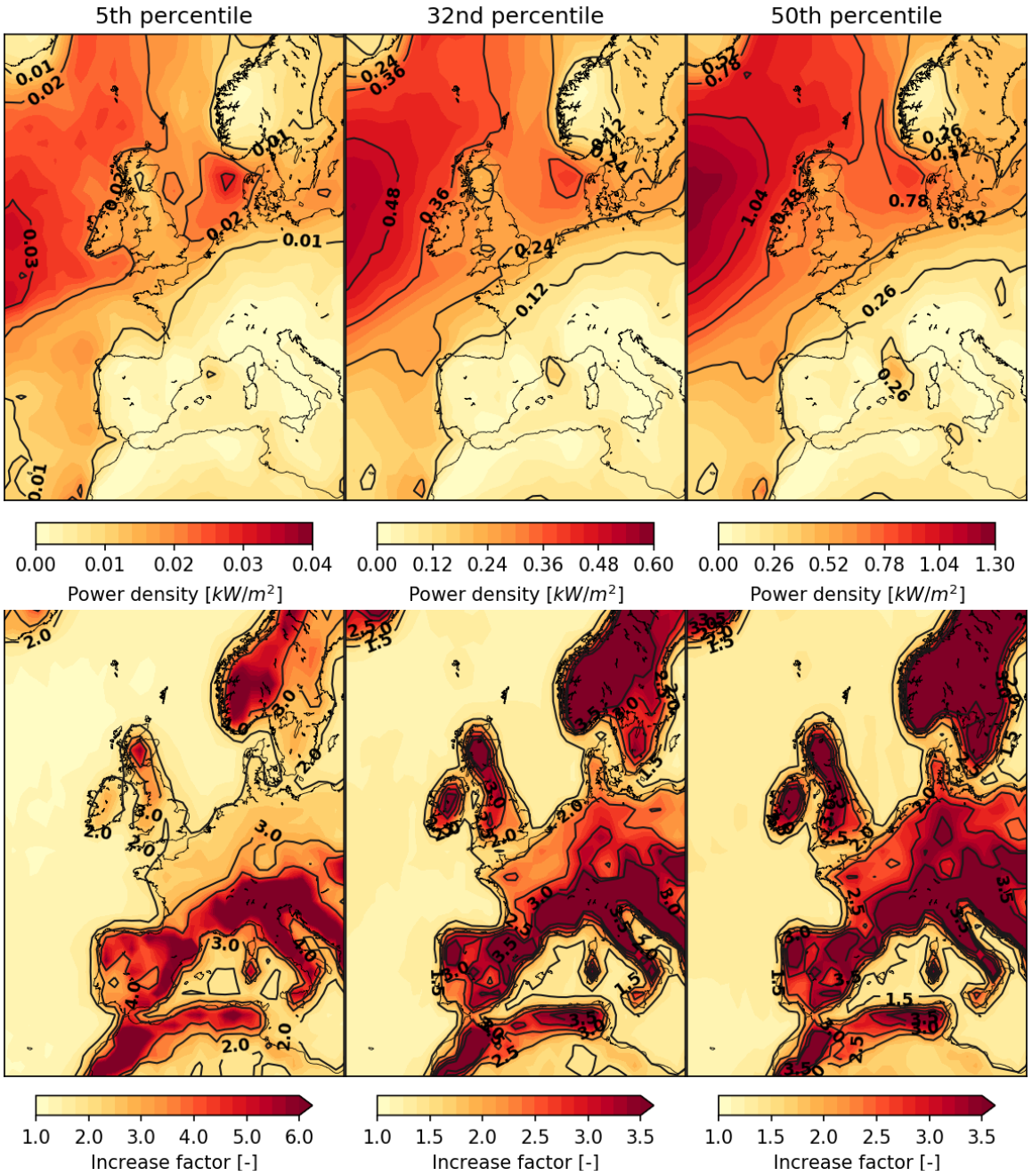


Average turbine hub altitude



Variable optimal AWE altitude

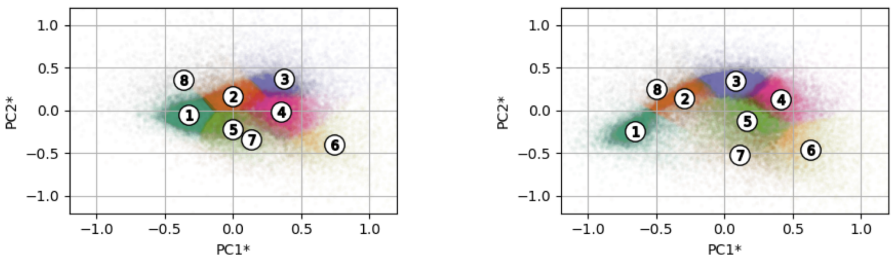
AWE Resource Potential Compared to Fixed Altitude



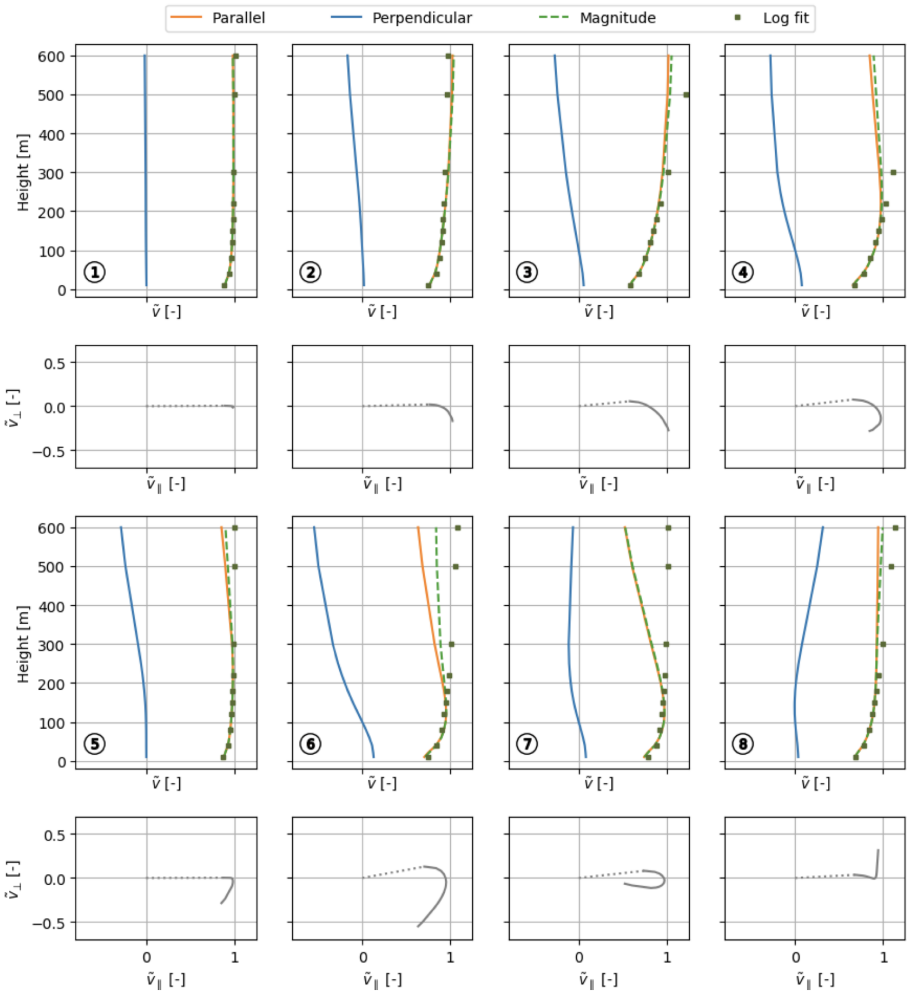
Characteristic Vertical Wind Profiles

from M. Schelbergen et al.:

- Cluster typical wind profiles

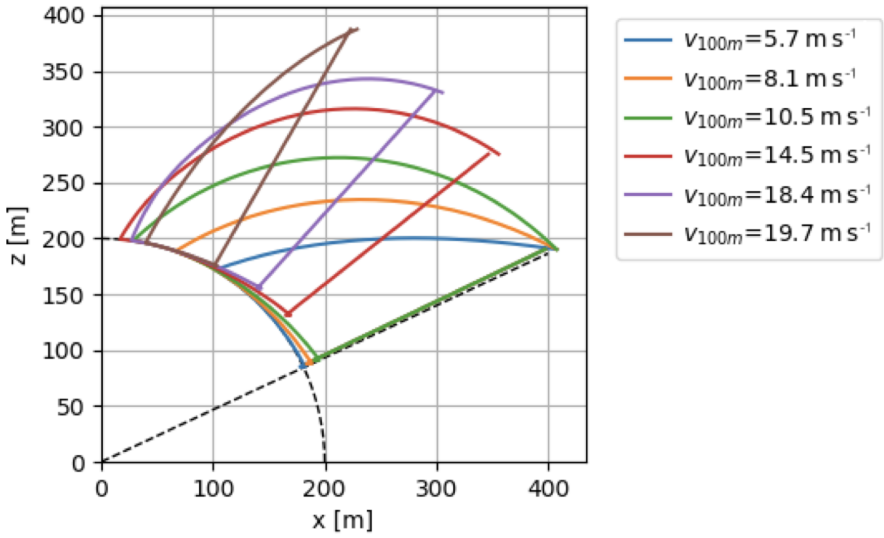


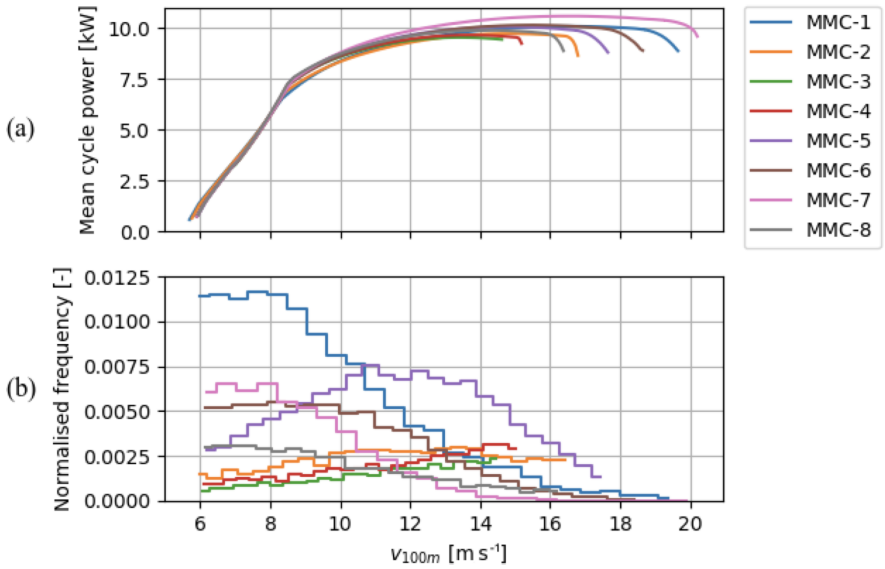
- Parametrize vertical wind profile in 3D at each location by using the PC cluster which works best, scale to the v_{100m} expected at that point of time and location



Towards Resource Potential with Power Charact. Optimized for Different Vertical Wind Profiles

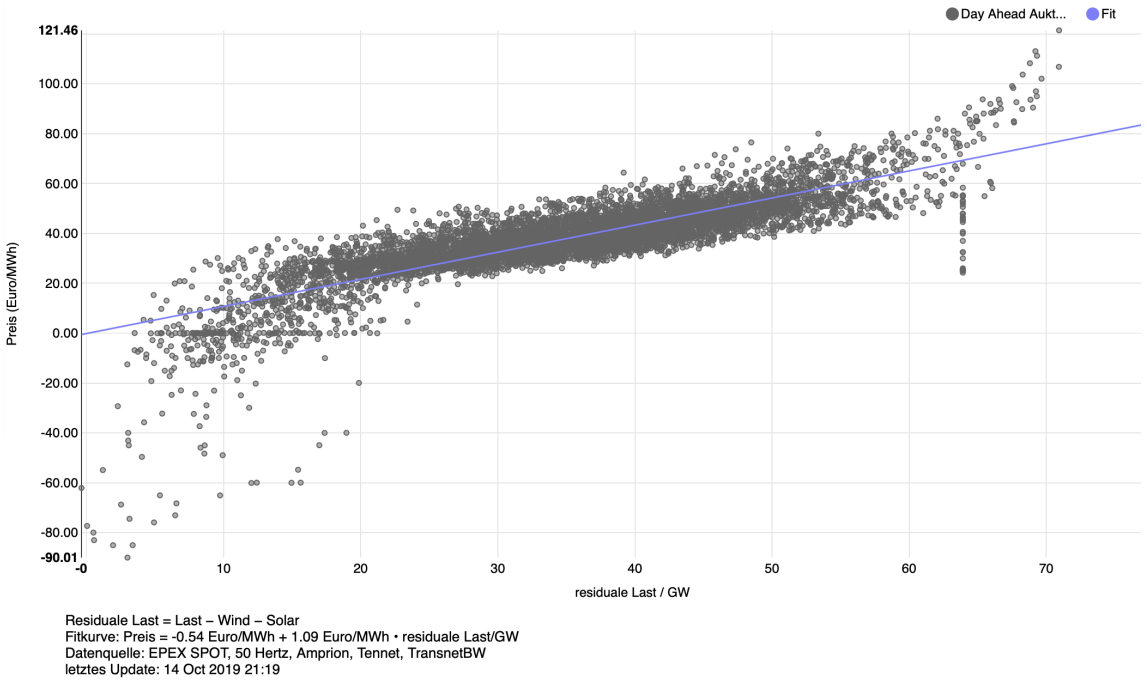
from M. Schelbergen et al.:

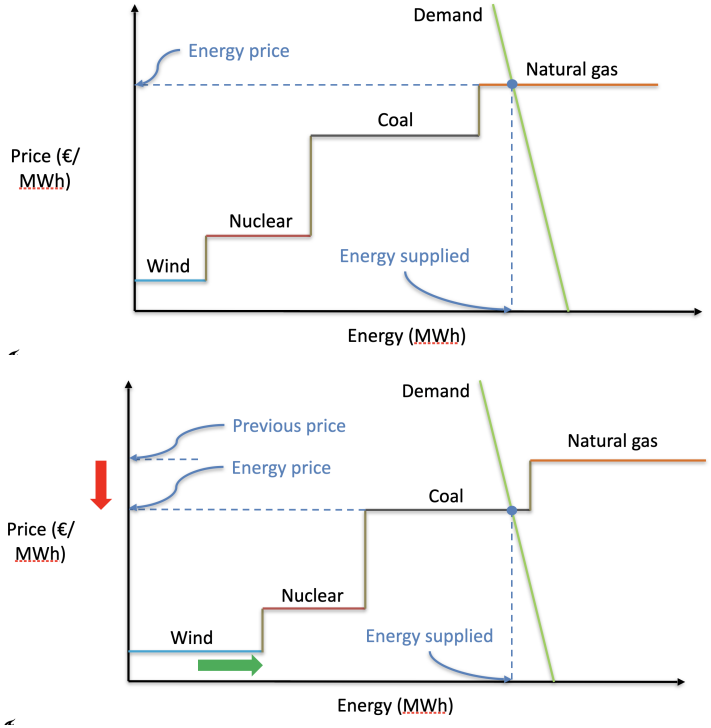




- for each vertical wind energy shape of each PC cluster, optimize the flight path
- scale the resulting power curve to the v_{100m} expected at that point of time and location

Beyond FLH and LCoE





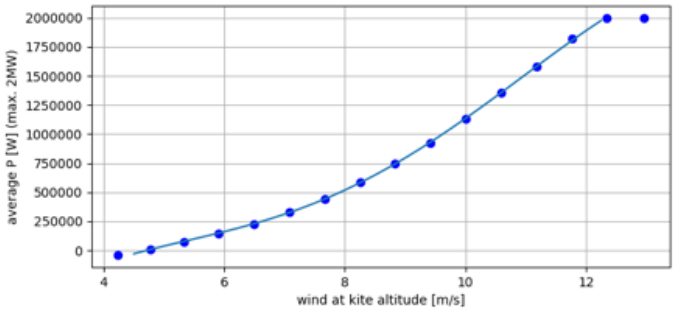
https://www.energy-charts.de/price_scatter_de.htm?source=priceVSResLoad&year=2019

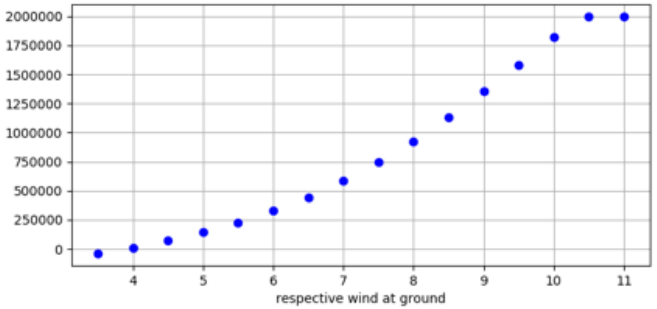
Day Ahead Spot Market prizes from

https://www.energidataservice.dk/dataset/elspotprices

Oversimplified simulation of the Power Curve of a 2MW pumping cycle AWE

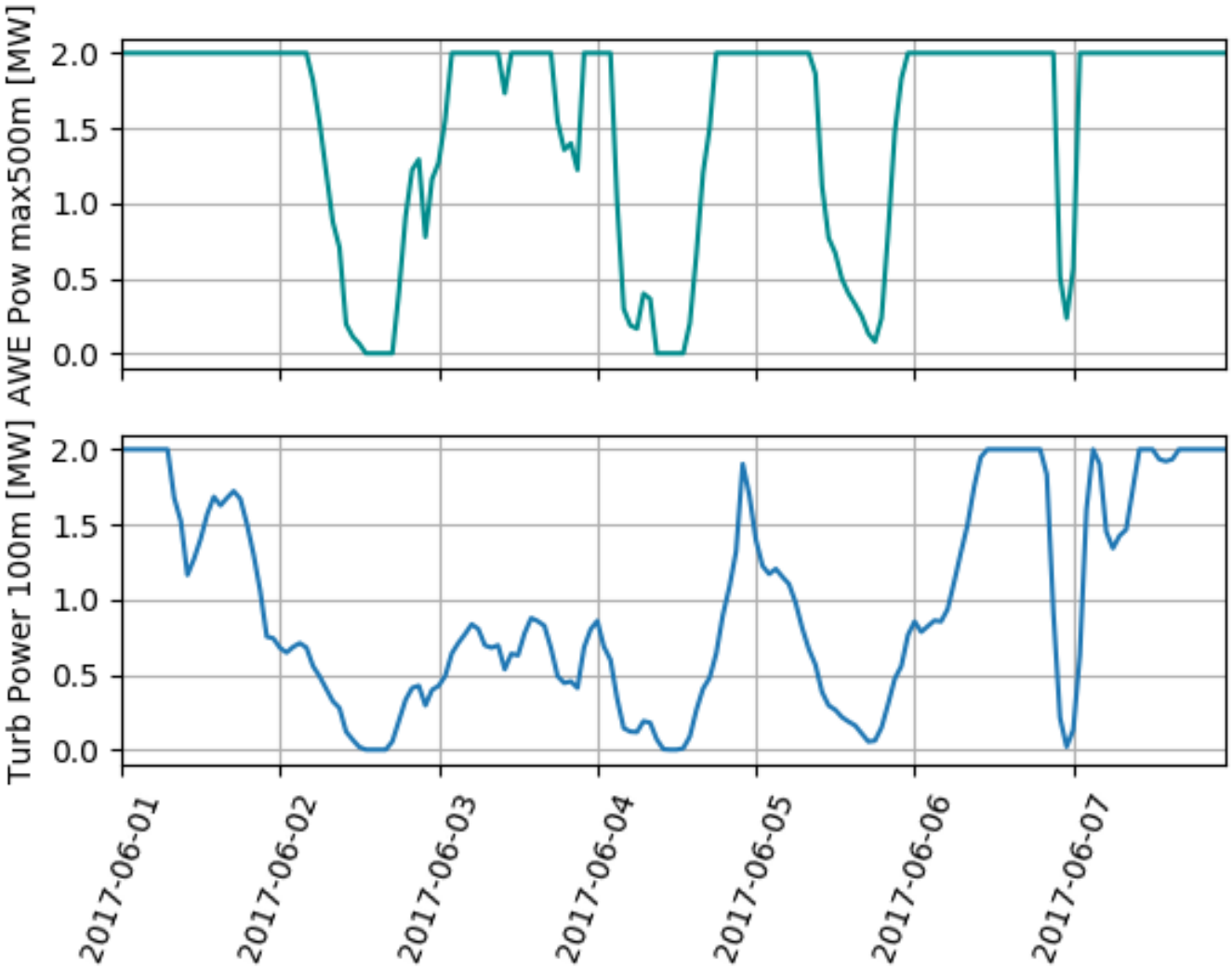
- 2MW Wing simulation with 6dof
- optimal control optimizing the average power over one cycle
  - amongst others optimize over
  - position, speed, rotation, wing control inputs
- Then scale the result for different tether angle and tether lengths
- cut-in 4.25 m/s, cut-out 22 m/s





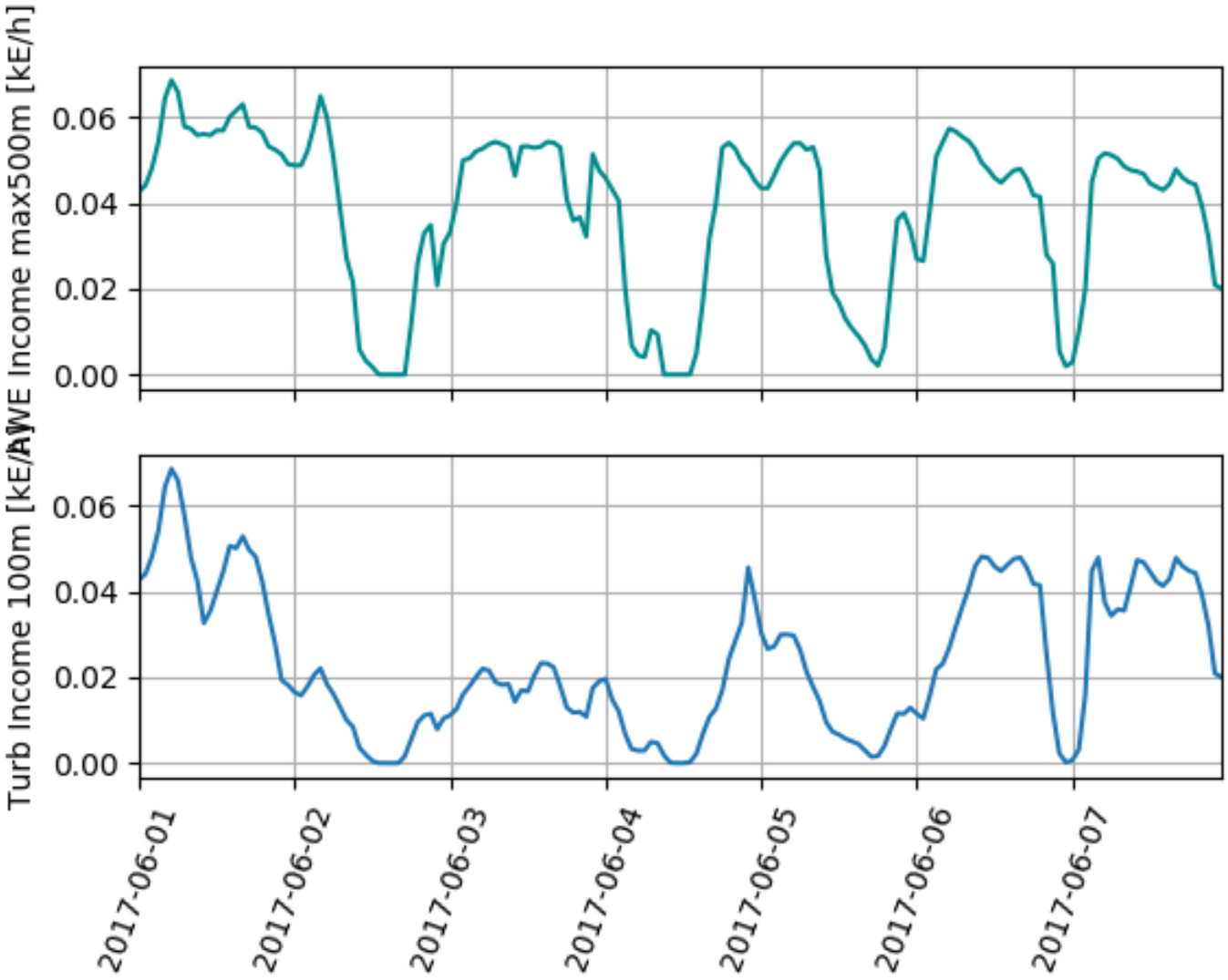
- Compare to a repowering turbine:
- REpower MM82 `https://www.thewindpower.net/store_manufacturer_turbine_en.php?id_type=7`

Power and Revenue Comparison AWE vs Turbine



Evaluated for the first week of June 2017

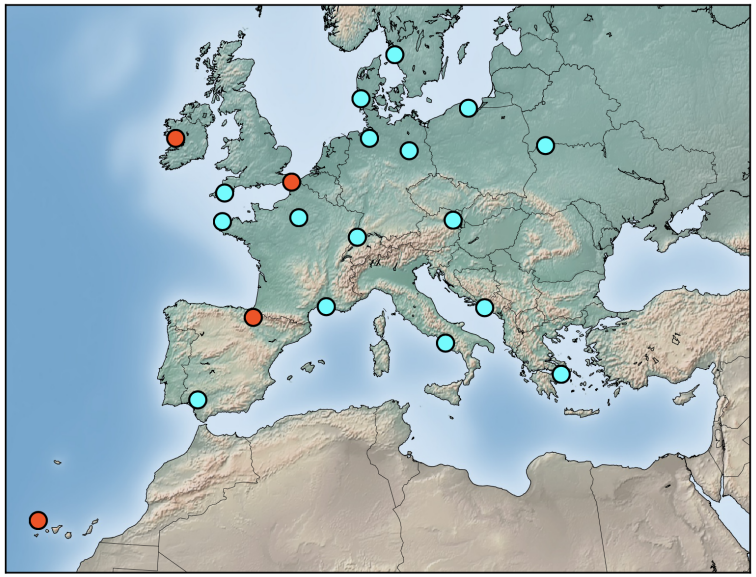
Power and Revenue Comparison AWE vs Turbine

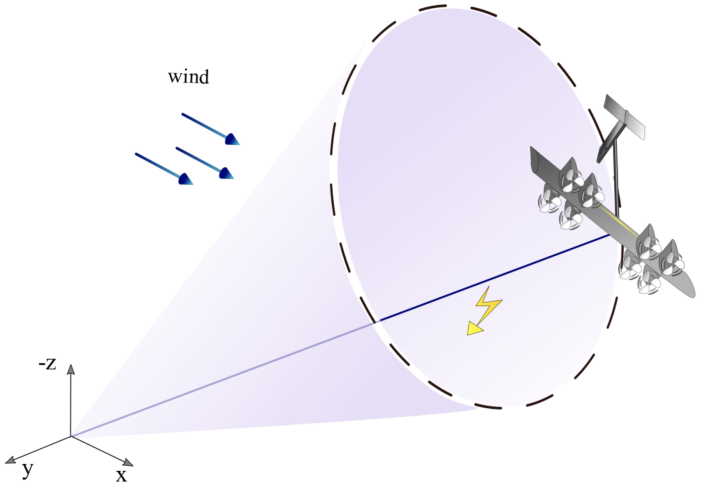


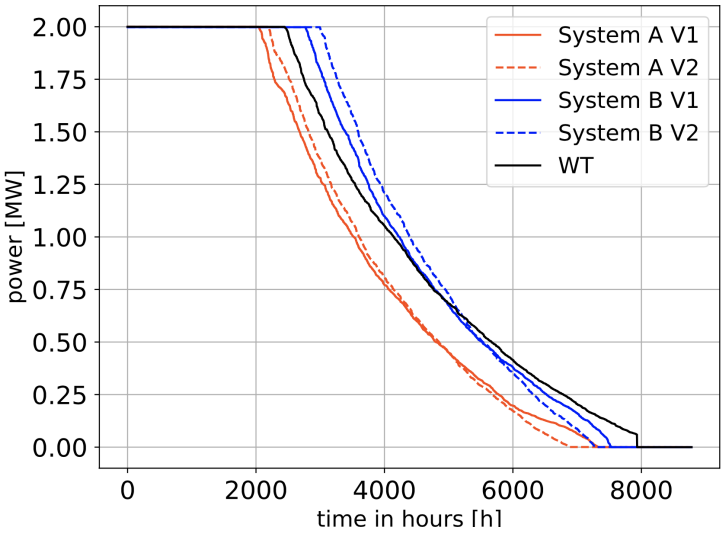
Evaluated for the first week of June 2017

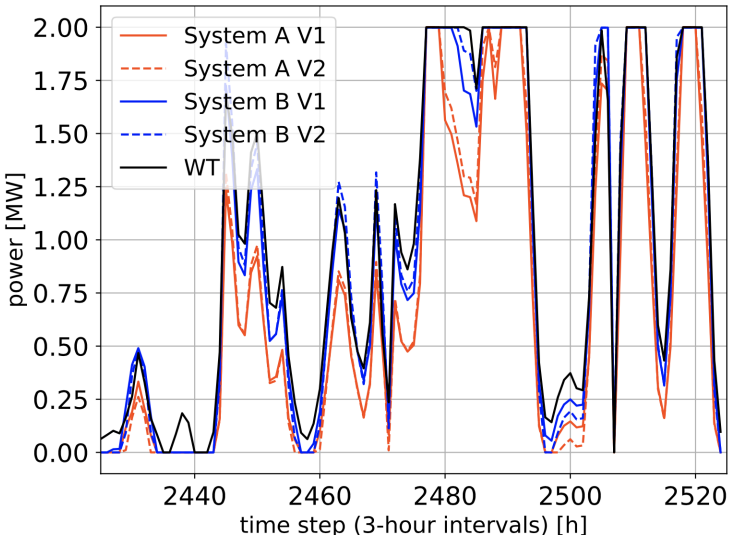
Market Penetration in Scenarios with very similar harvesting characteristics of AWE and WT

from E. Malz et al.:



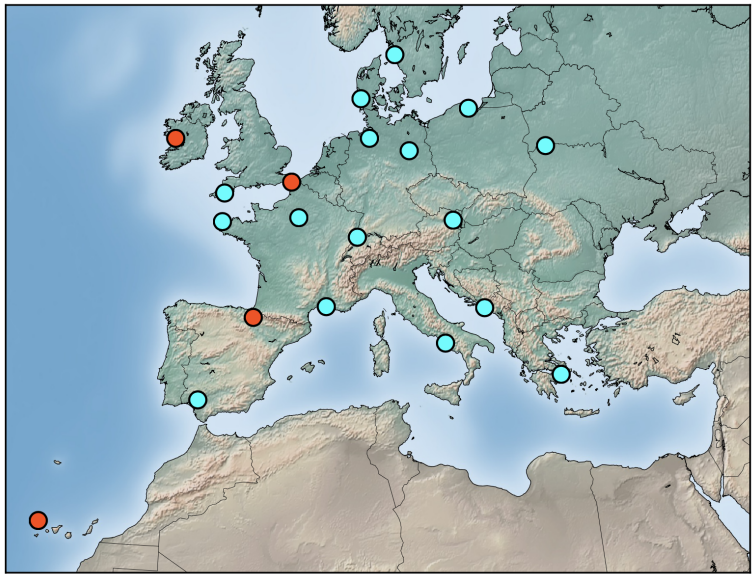


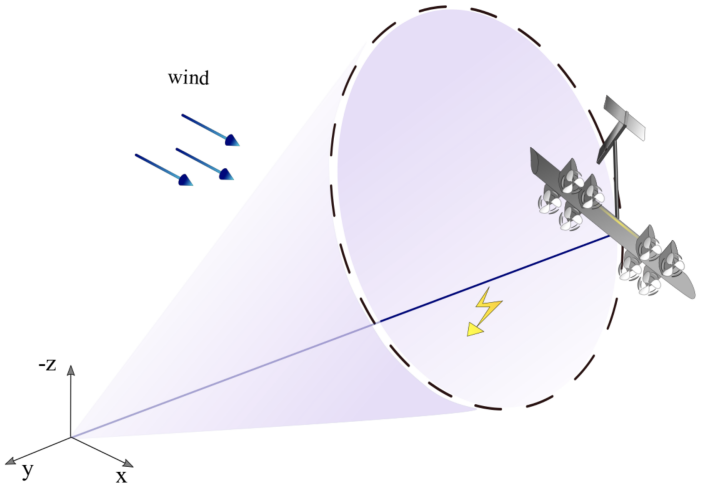


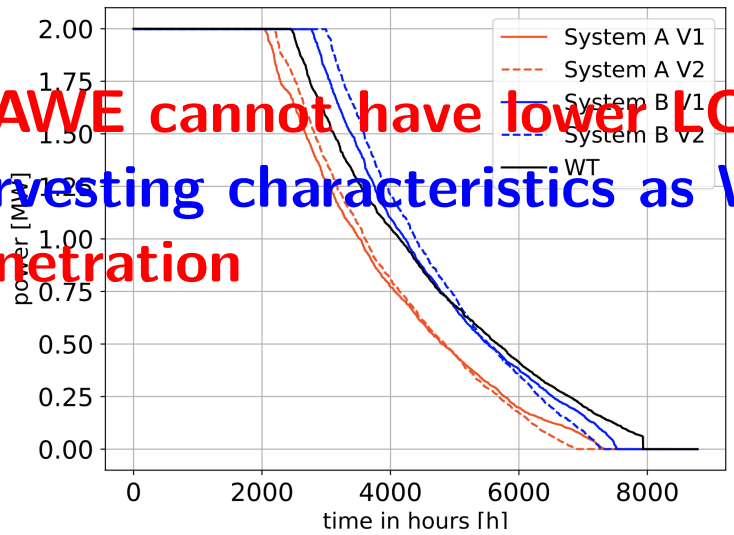


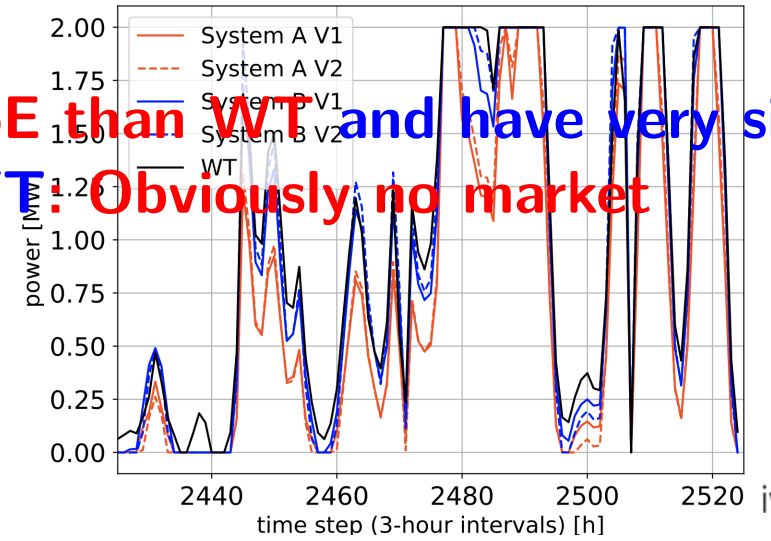
Market Penetration in Scenarios with very similar harvesting characteristics of AWE and WT

from E. Malz et al.:









- **If AWE cannot have lower LCoE than WT and have very similar harvesting characteristics as WT: Obviously no market penetration**

Outlook

- In a revenue scenario based on spot market prizes, optimize for net present value NPV:

$$NPV = \sum_t E(t)(LRoE(t) - LCoE)$$

  (ongoing, e.g. Master Thesis TU Delft, Ampyx Power by R. Joshi)
- Under this objective, expect to optimize power characteristics for lower wind speeds
- Make integration of power characteristics in resource potential code more realistic (optimal path not only depends on vertical wind profile)
- Include realistic shadowig effects for wind parks, optimize operations in wind park differently than for single AWES
- For the ultimate outlook on the potential effect of AWE on a 100 % Renewable Energy scenario:
  Collaborate with energy system modelling experts. First contacts e.g. to Christian Breyer, Samuli Honkapuro, LUT University, Finland,
  see example simulation

universitätbonn

Summary

- Resource potential itself well understood, thanks to e.g. ERA5 re-analysis
- Reference model simulation well underway
- Sophisticated implementations of power characteristics in wind resource models being developed
- If the power harvesting characteristics of AWE is similar to that of conventional wind, expect not much penetration power!
- Found potential for significant revenue increase in a spot market (Deay Ahead) prizing scenario if increased capacity factor and optimization for low wind speeds can be realized
- First example with oversimplified scaling of power characteristics for AWE and WT with 2 MW nameplate capacity: 01-07. June 2017: Turbine 3976 Euro, AWE 6404 Euro
- Wind resource data and public analysis code:
  - `https://github.com/rschmehl/awe-era5/`
  - `https://we.tl/t-tZWsIQJ5pf`

universitätbonn

References

- The main resources from this talk are:
- Resource Potential:
  PB, M. Schelbergen, R. Schmehl, S. Watson, U. Zillmann,
  "Airborne wind energy resource analysis",
  Renewable Energy V.141, Oct. 2019, P. 1103-1116
- Reference Design:
  D. Eijkelhof et al.,
  "Reference Design and Simulation Framework of a Multi-Megawatt Airborne Wind Energy System"
- Power Curves and Resource Potential:
  - E. Malz et al.,
    "Drag-mode airborne wind energy vs. wind turbines: An analysis of power production, variability and geography ", Energy V. 193, 15 Feb. 2020, 116765
  - M. Schelbergen et al.,
    "Clustering wind profile shapes to estimate airborne wind energy production",
    Wind Energ. Sci., 5, 1097-1120, 2020
- Further work in this direction is ongoing in OEMs and Academia

universitätbonn

Backup Slides

The ERA5 Wind Data Set from the ECMWF

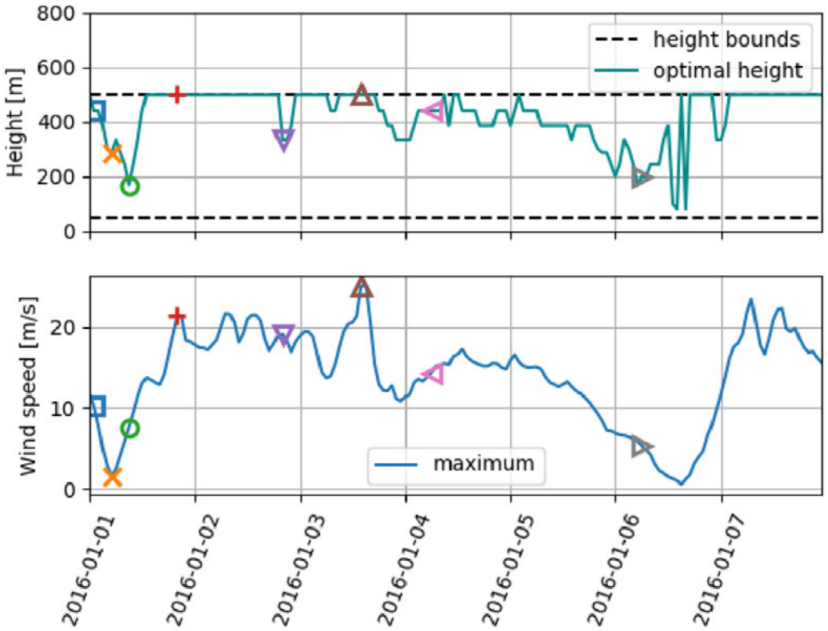
ERA5 combines vast amounts of historical observations into global estimates using advanced modelling and data assimilation systems. Access to all observations used in ERA5 will be provided at a later stage.

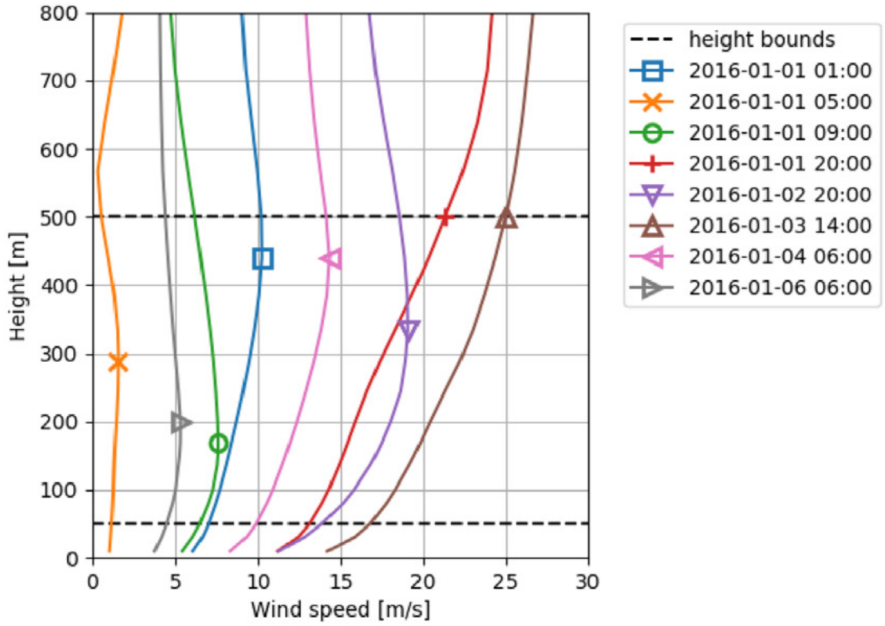
ERA5 replaces the ERA-Interim reanalysis which stopped being produced on 31 August 2019. You can read about the key characteristics of ERA5 and important changes relative to ERA-Interim.

`https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5`

universitätbonn

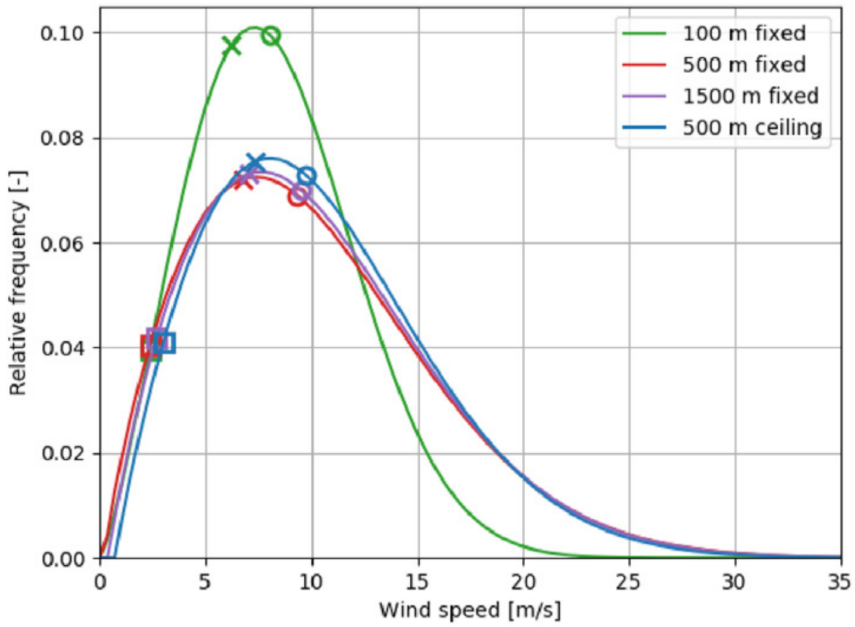
Integrating AWE core capabilities into the Source Potential

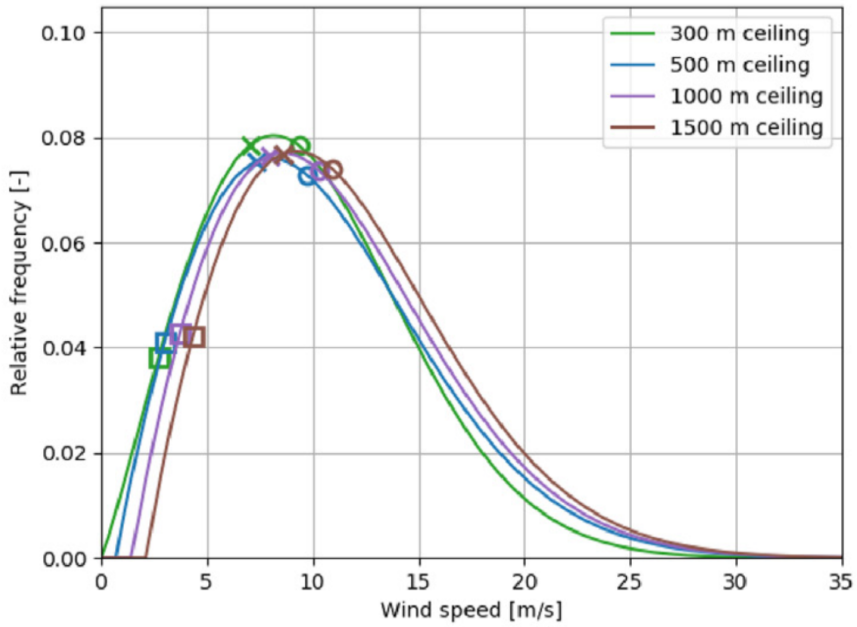




- For every location on a $1^\circ \times 1^\circ$ map, find the optimal wind speed below a given ceiling for every hour from 2010 to 2017
- Find dramatically improved wind at variable height compared to fixed altitudes

Integrating AWE core capabilities into the Source Potential



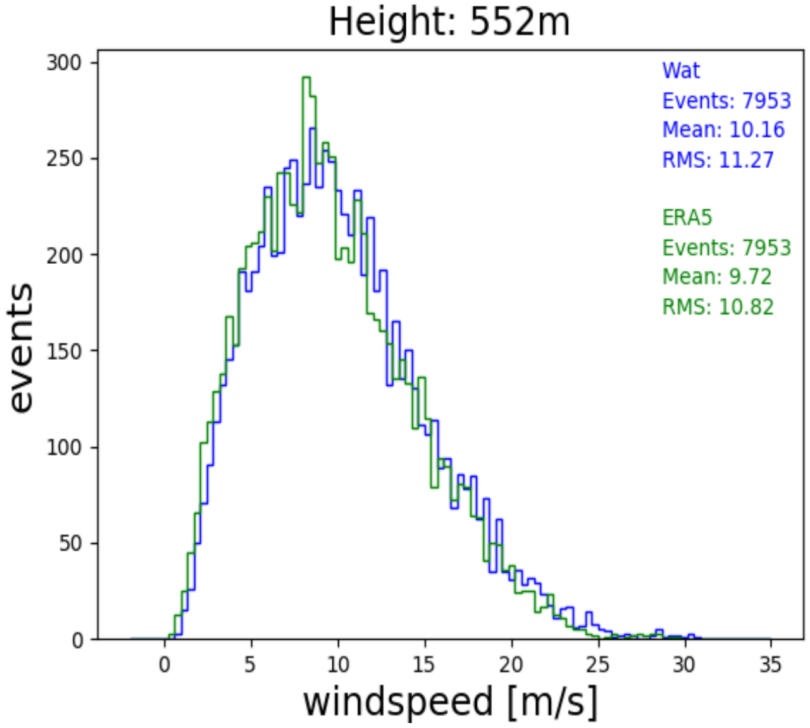


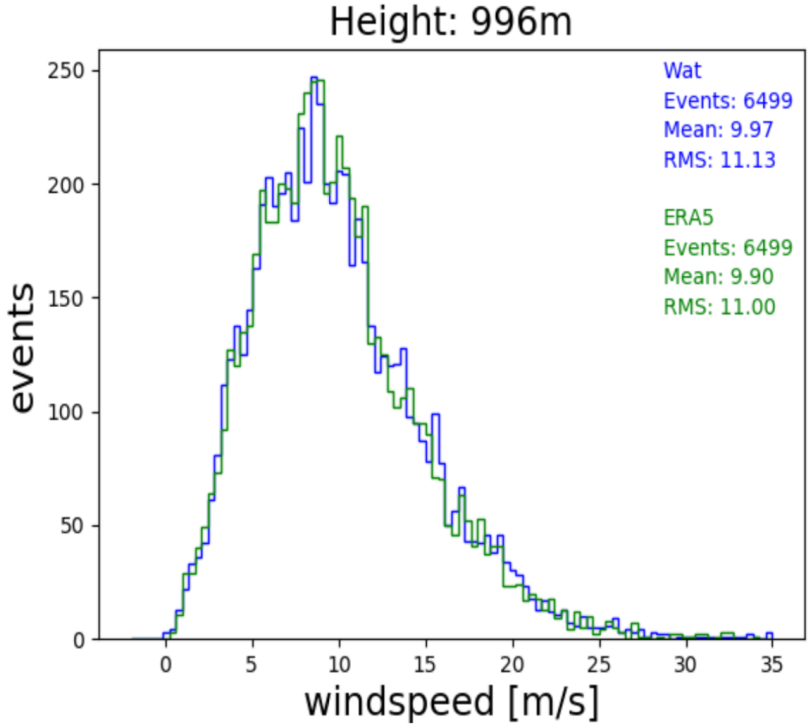
- For every location on a $1^\circ \times 1^\circ$ map, find the optimal wind speed below a given ceiling for every hour from 2010 to 2017
- Find dramatically improved wind at variable height compared to fixed altitudes

Compare ERA5 to an independent dataset

from Master Thesis by Max Rüger, Univ. Bonn:

- Use Met Office LIDARNET measurement at Wattisham airfield, GB
- Compare overall distributions at different relevant altitudes

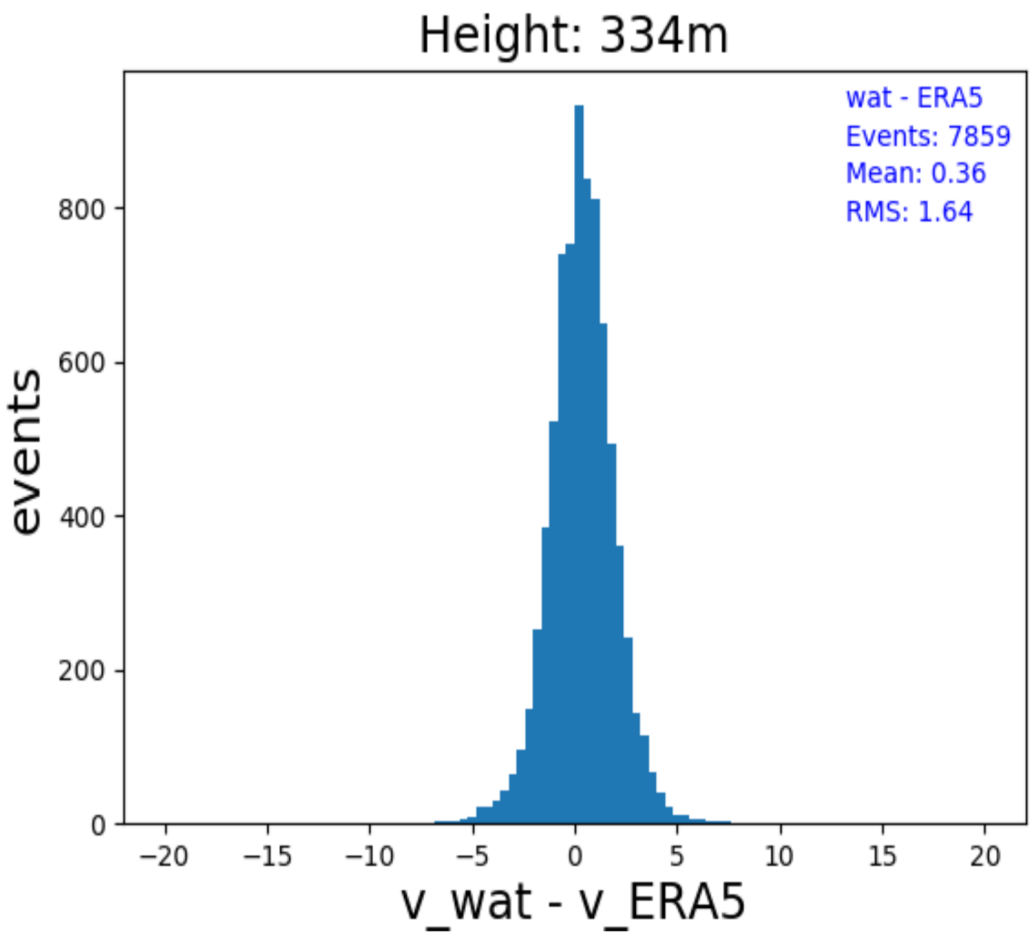




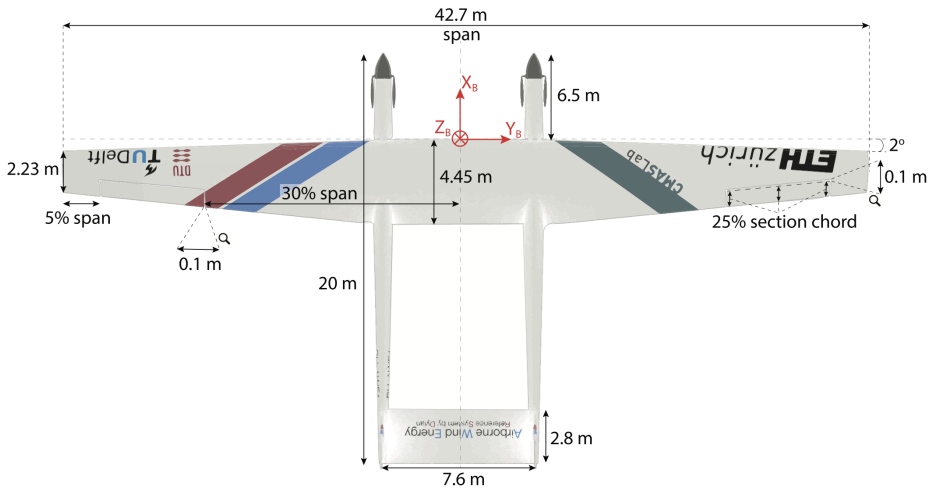
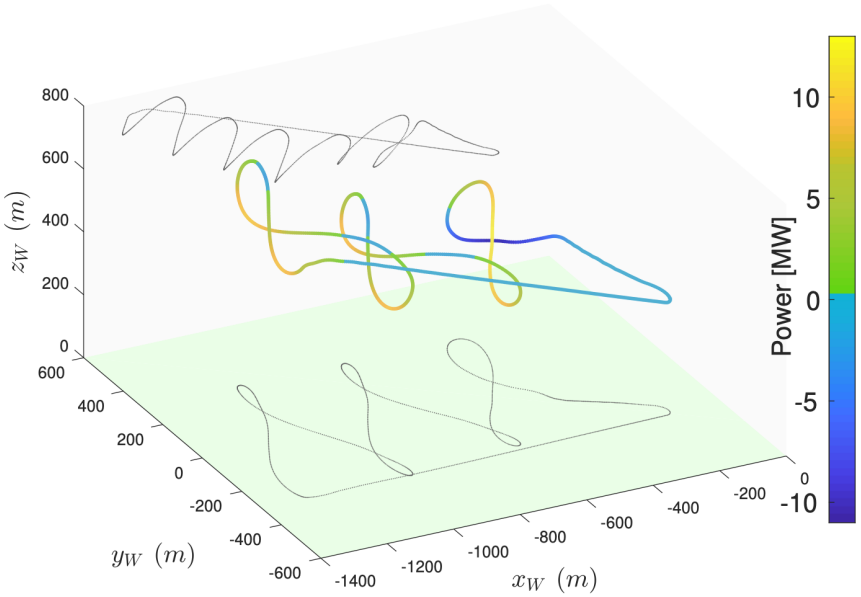
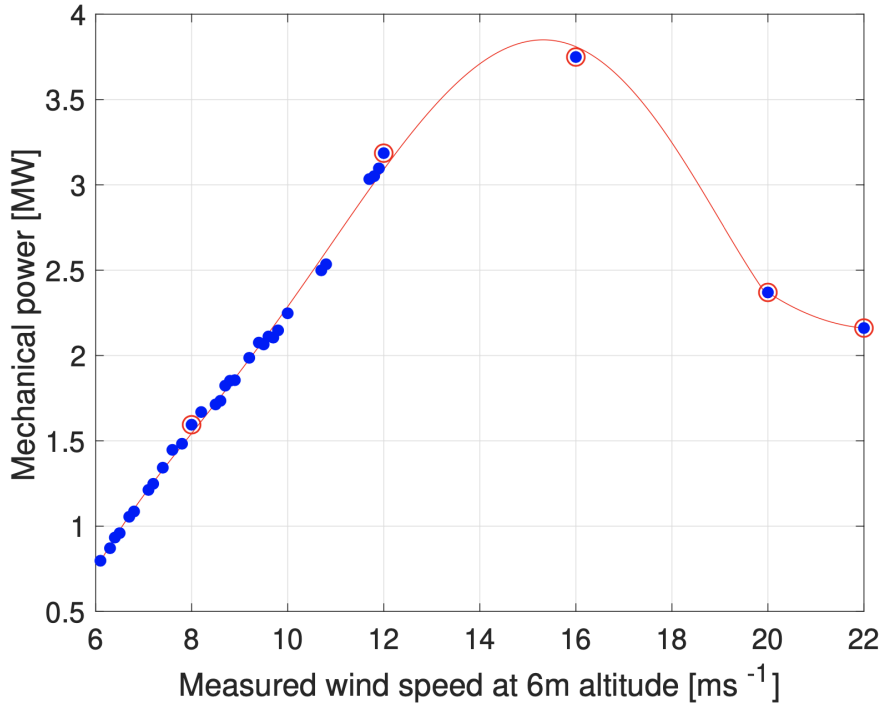
Compare ERA5 to an independent dataset

from Master Thesis by Max Rüger, Univ. Bonn:

- Determine measurement uncertainty from 2 independent LIDARs at the same site
- Quadratically subtract measurement uncertainty
- Time-resolved uncdertainty of ERA5 $\sigma \approx 1.3\,\mathrm{m/s}$



from D. Eijkelhof et al.: Reference Models



Flight path	Tether force	Controller
Figure-of-eight roundness a	Traction force set point	K_p winch
Figure-of-eight width b	Retraction force set point	K_i winch
Elevation angle		Transition elevation angle
Minimum tether length		Initial path elevation angle
Maximum tether length		$K_{p,\chi}$ traction
		$K_{p,\gamma}$ traction
		$K_{p,\chi}$ retraction
		$K_{p,\gamma}$ retraction
		$K_{i,\chi}$ retraction
		$K_{i,\gamma}$ retraction
		ω_{0,μ_a}
		ω_{0,α_a}
		$\omega_{0,\chi}$ retraction
		$\omega_{0,\gamma}$ retraction