HAW HAMBURG | CC4E

University of Strathclyde Glasgow

RENEWABLE DYNAMICS

MRS, selected key factors

Multi Rotor Seminar 2025, Hamburg University of Applied Sciences

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WIND CATCHING

Agenda

- Introduction
- MRS – definitions and impressions
- MRS – selected key factors
- Challenges and research needs

Model Lutz Rohlfing

Offshore Wind

No bidders in recent auctions (Germany, Denmark)

Quantitative and qualitative criteria:
Sustainability and local production

Resilience, cyber security, Innovation

Rotors still getting bigger, but increasing problems (supply chain, reliability, development costs, …)

Powerhouse Europe

- Powerhouse Europe 300 GW until 2050
- Germany 2050: 70 GW Offshore Wind

  → Huge wake effects

  → Equivalent full load hours drop from

  > 4000 h/a to < 3000 h/a for some areas

  →Wind industry demands reduction to

  50 GW goal, because of wake losses

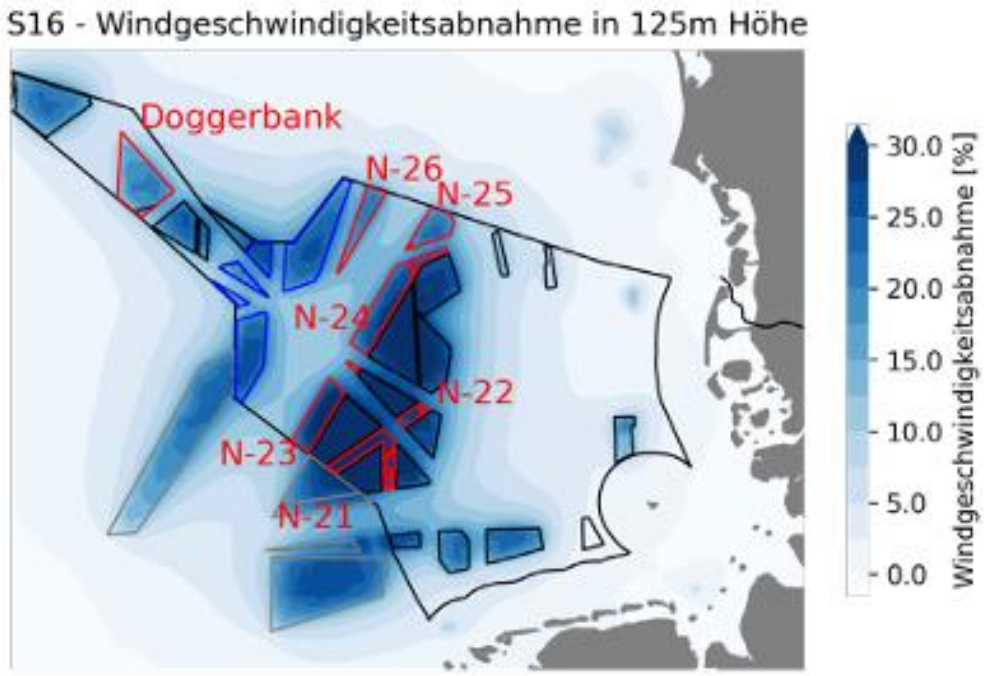
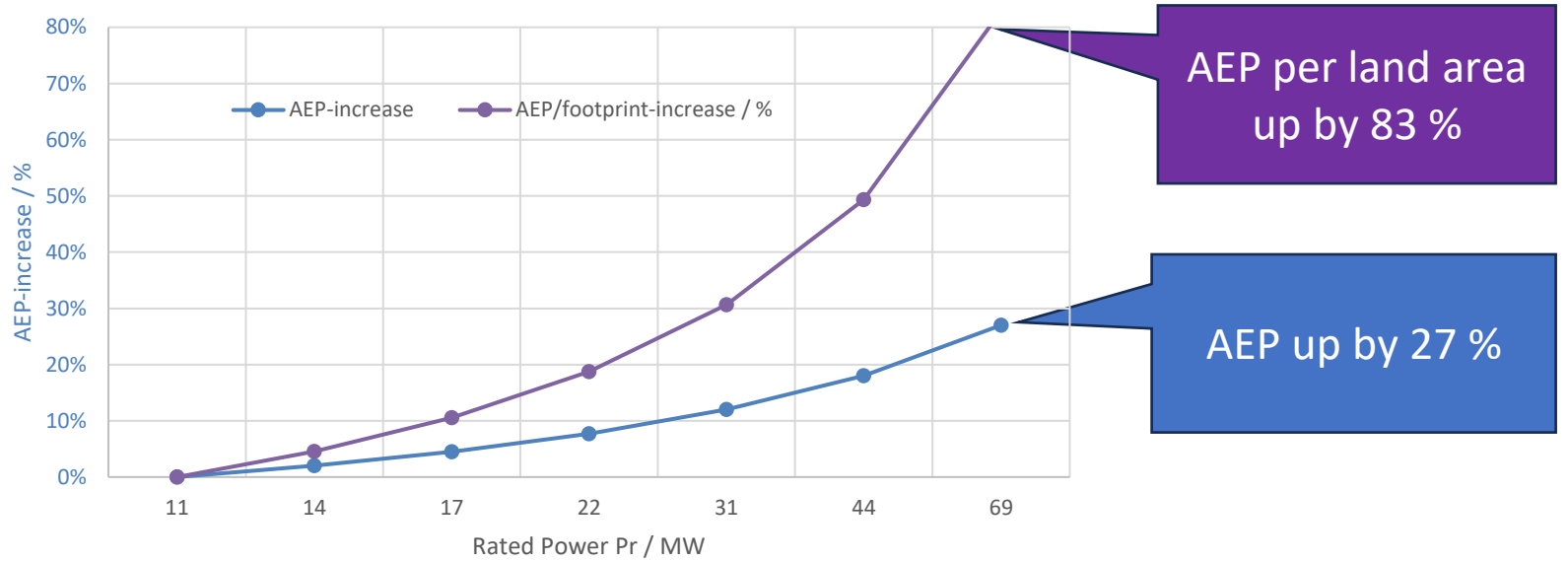


Figure by Fraunhofer IWES 2023: Reduction in wind speed (%) due to wake effects

Energy Yield per Land Area

- 1100 MW wind farm with turbines from
  100 x 11 MW to
  16 x 68.75 MW
  (single rotors),
  6D spacing
- Avg wind speed 10.2 m/s in 105 m height, z_0 = 0.1
  AEP based on „A Minimalistic Prediction Model to Determine Energy Production and Costs of Offshore Wind Farms“, by J. Sorensen and G. Larsen, Energies 2021

1100 MW-wind farm, 6D spacing (Sorensen-Larsen-minimalistic model)



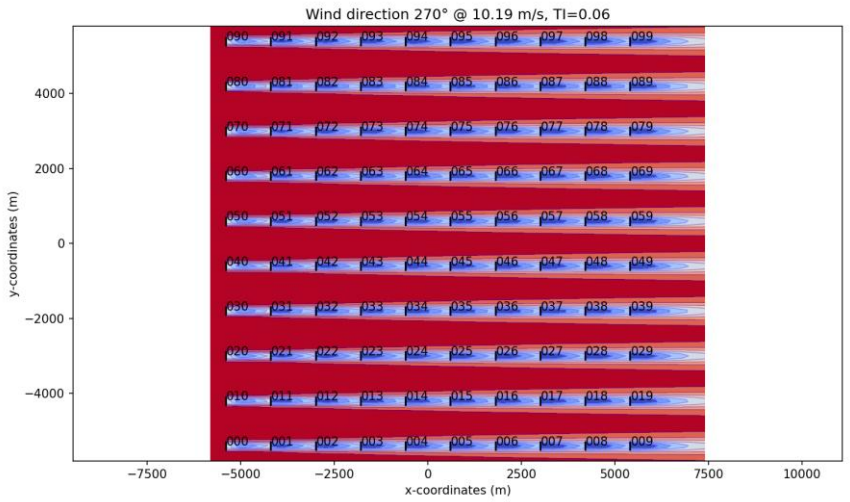
Number of turbines	100	81	64	49	36	25	16
Rotor diameter	200	222	250	286	333	400	500

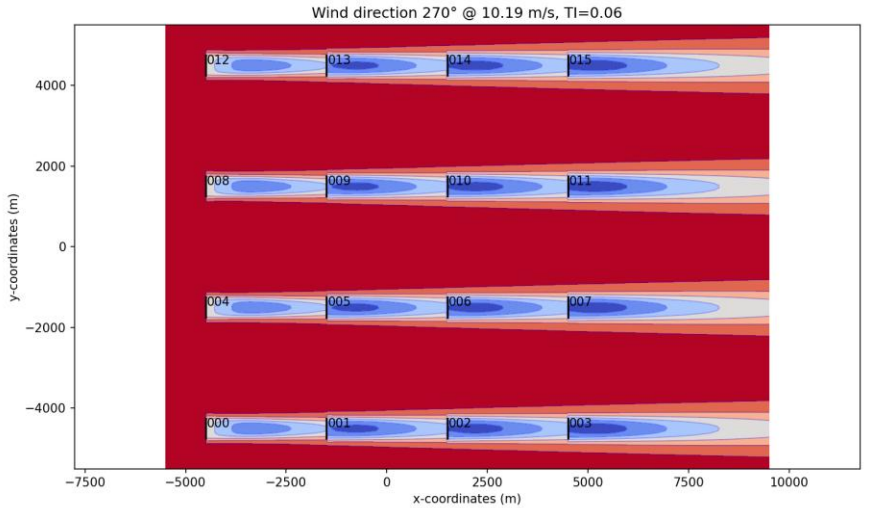
Source: HAW Hamburg / CC4E

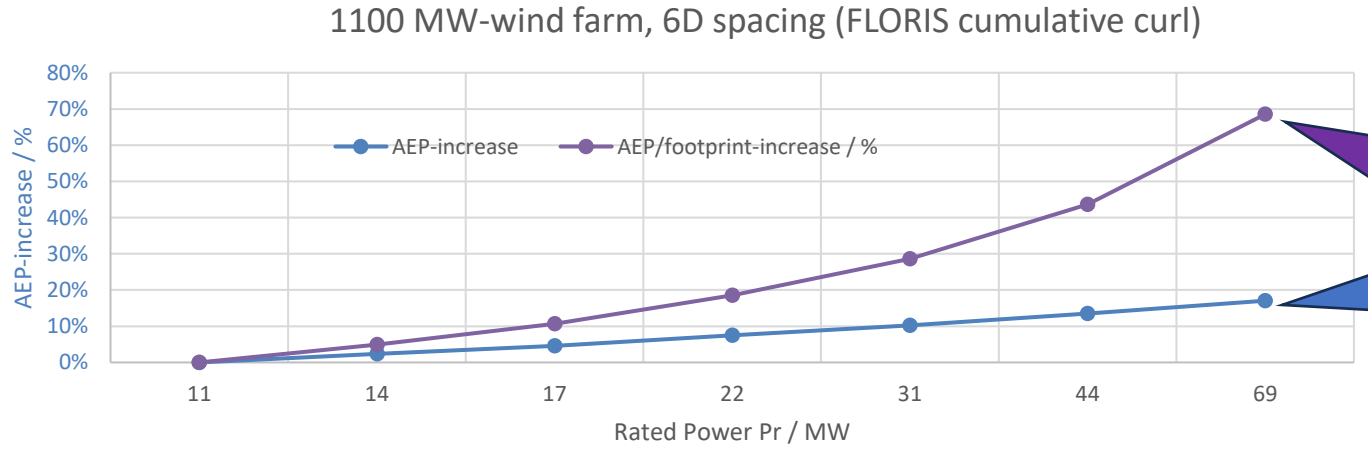
Energy Yield per Land Area, FLORIS simulation

- Validation with FLORIS delivered similar qualitative results, but less pronounced
- Uniform wind direction distribution
- Cumulative Curl-Model
- α = 0.12
- **AEP up by 17% for 16 x 68.75 MW versus 100 x 11 MW**

- Preliminary results and not yet compared with cfd-LES







Source: HAW Hamburg / CC4E

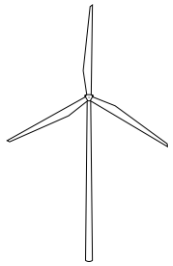
MRS, selected key factors

Multirotor Categories

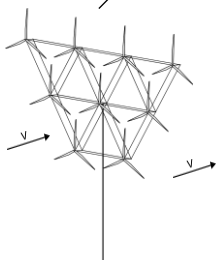
Wind Energy

Single Rotor

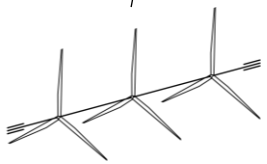
HAWT



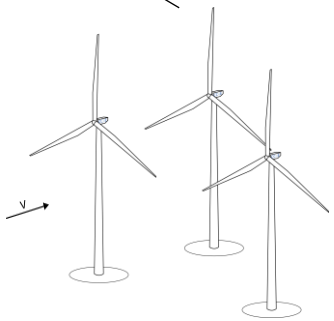
Multirotor (HAWT)



Co-Planar



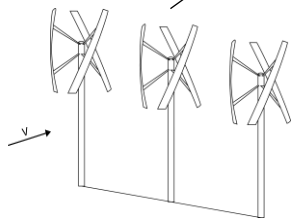
Co-Axial



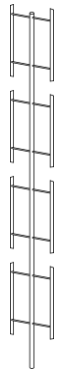
Co-Planar & Co-Axial: Wind Farm

VAWT

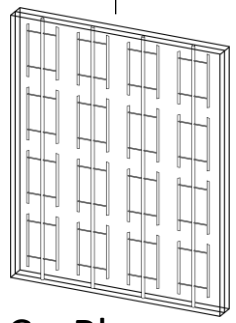
Multirotor (VAWT)



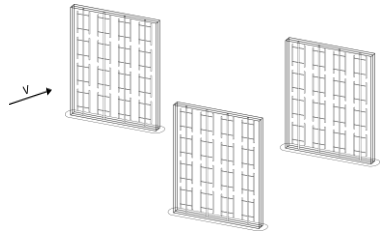
Co-Planar



Co-Axial



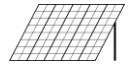
Co-Planar & Co-Axial



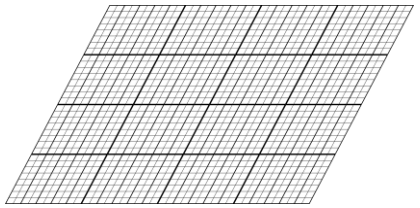
Wind Farm

Solar-PV

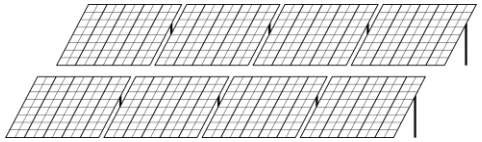
Single Module



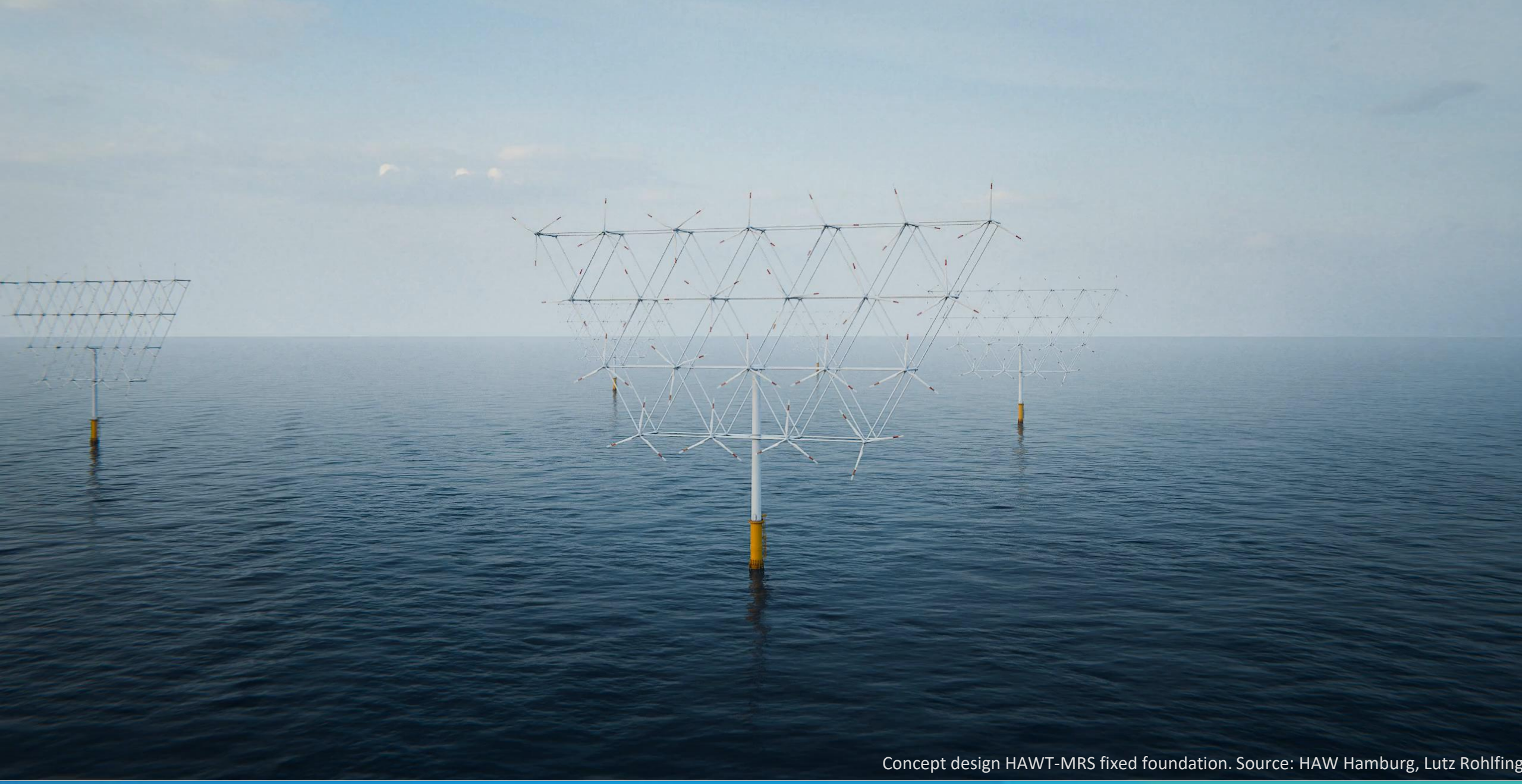
Multi-Modules



Co-Planar (e.g. rooftop mounted)



Mixed



Concept design HAWT-MRS fixed foundation. Source: HAW Hamburg, Lutz Rohlfing

Concept design VAWT-MRS floating foundation. Source: HAW Hamburg, Lutz Rohlfing

MRS design features

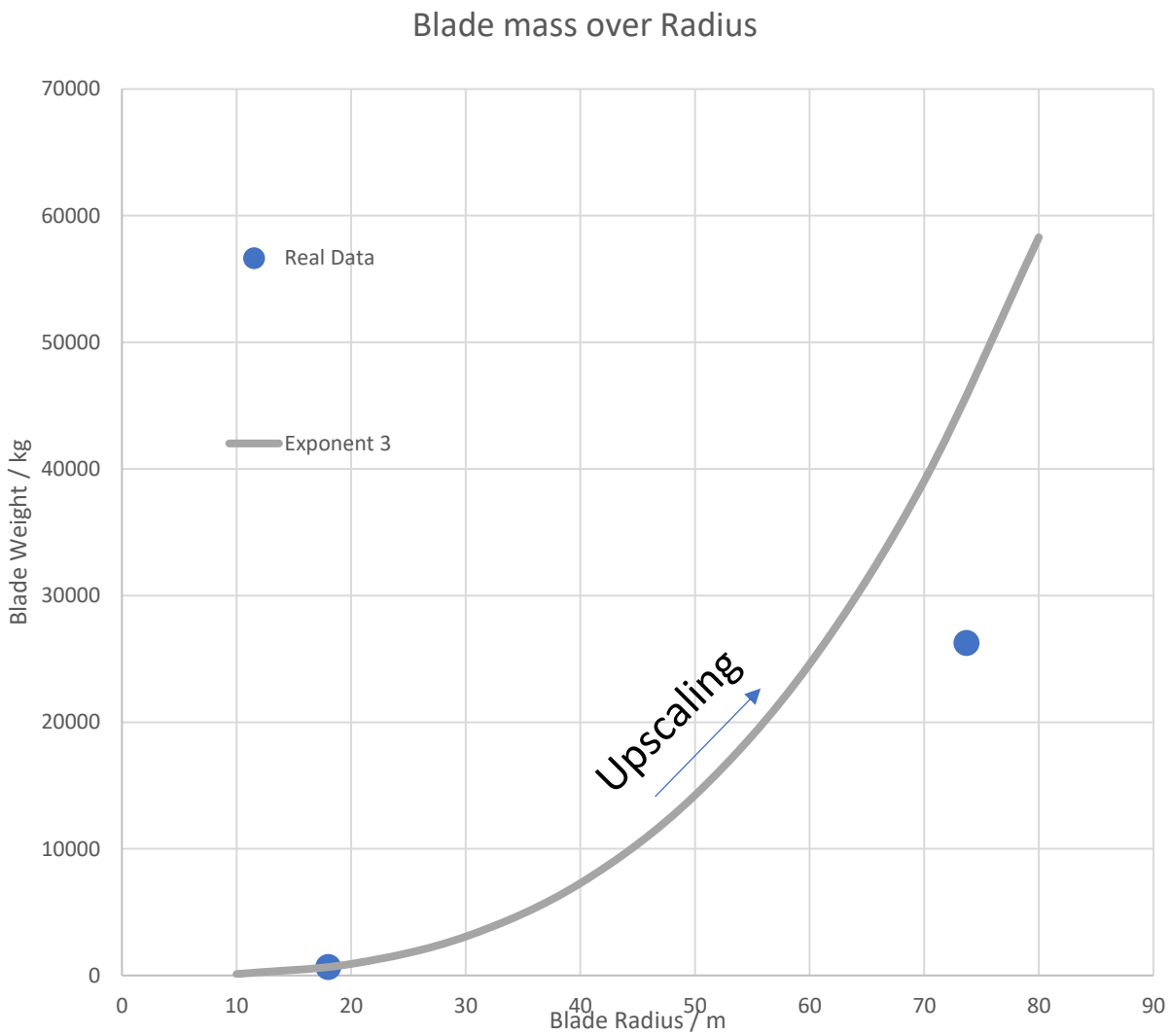
Cantilever	Windbrücke	Enerocean	OceanX	Myriad	Space Frame
Two Rotors					Many rotors
Onshore					Offshore
Fixed Foundation					Floating Foundation
Small Rotors					Big Rotors

Morphological Box of MRS in the sub-category horizontal axis, co-planar

Scaling Up & Down & Down & Up

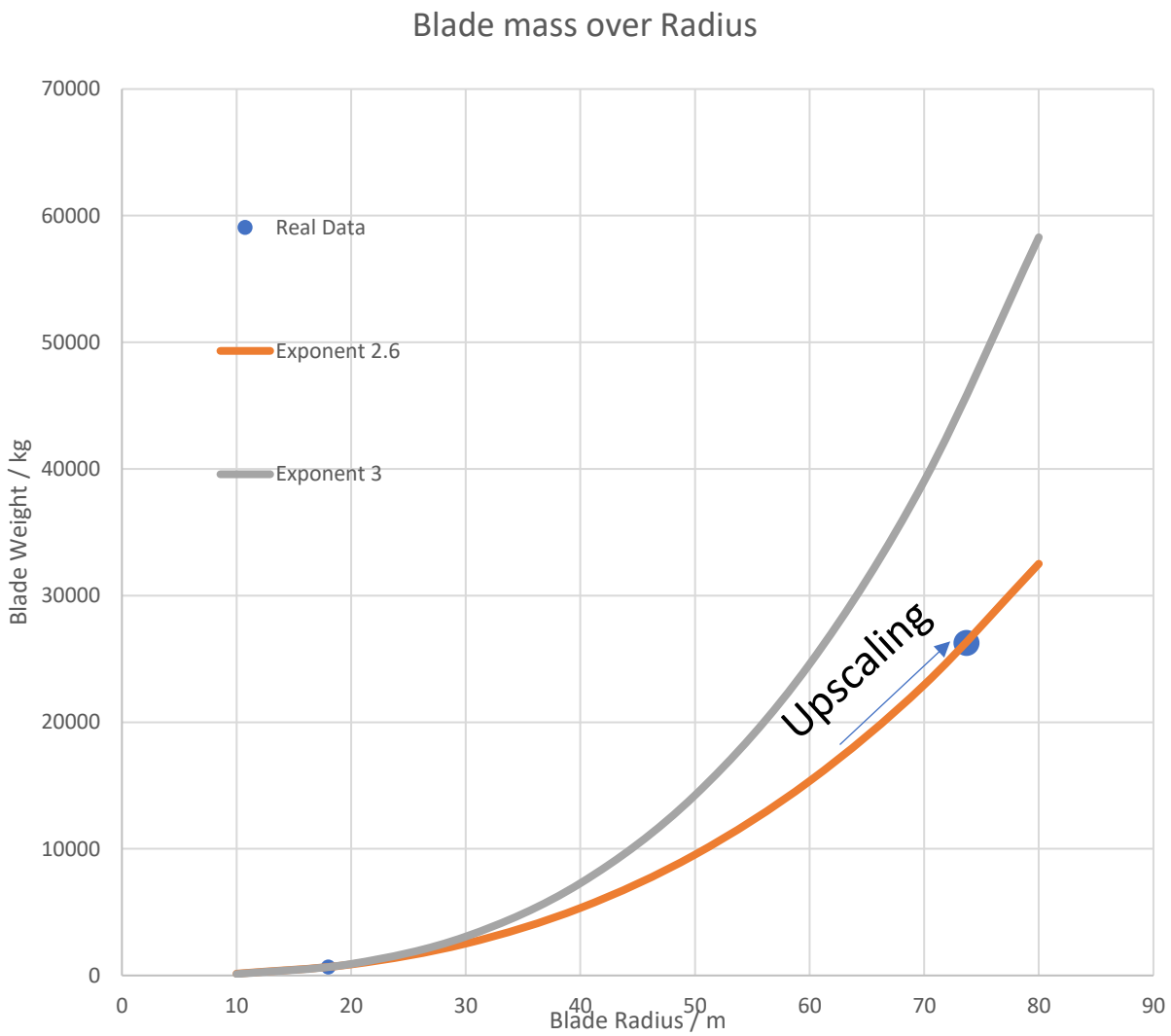
- Upscaling with Exponent k=3 according to Square-Cube-Law
- Does not match real data, since approx. 40 years of development and innovation in the wind industry between short old and long new blades

$$M = m_{ref} \left(\frac{D}{d_{ref}} \right)^{k}$$



Scaling Up & Down & Down & Up

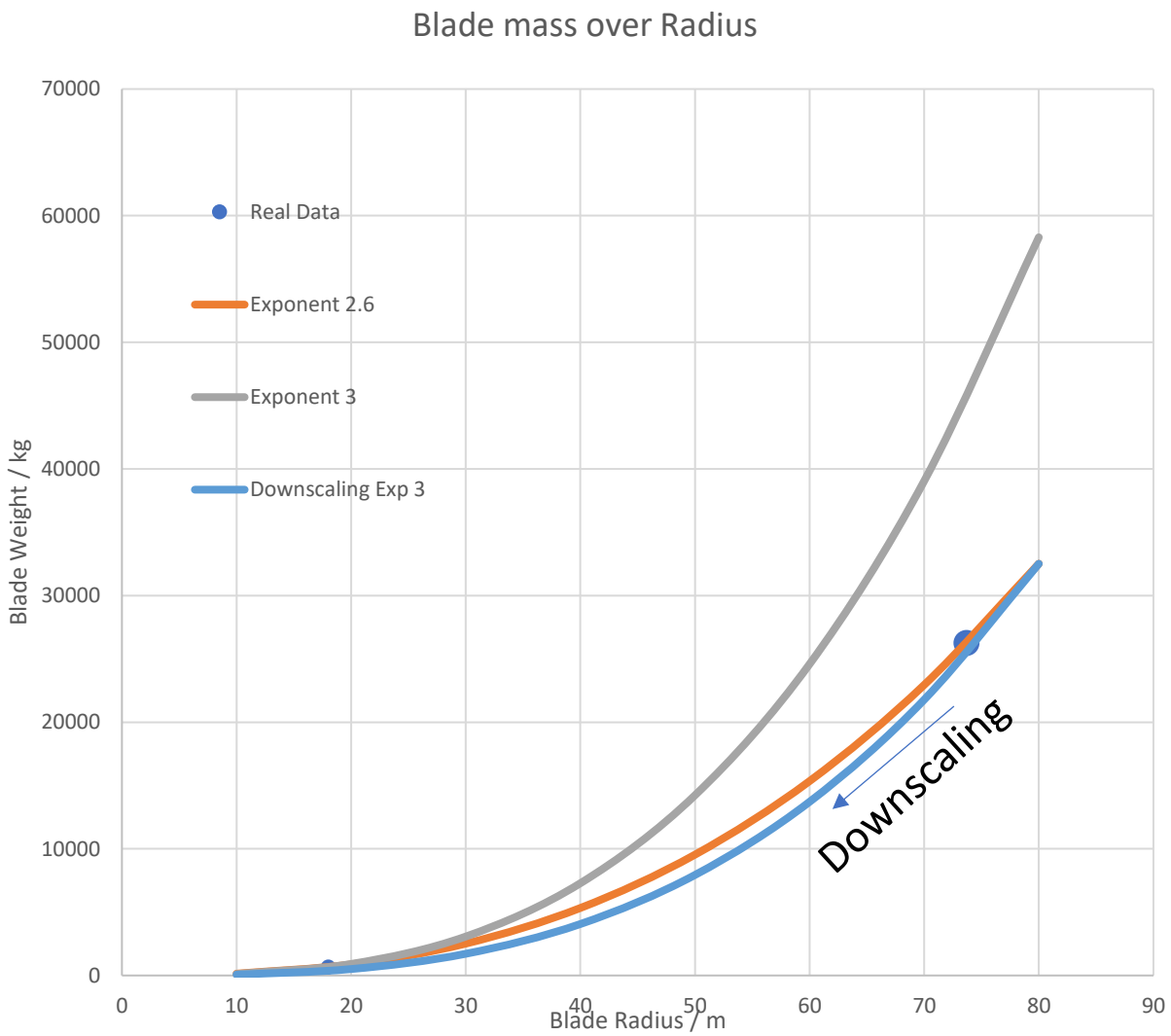
- Upscaling with k=2.6 better matches real data.
- This does not prove square-cube law wrong. It just incorporates learning curves of the wind industry.
- Extrapolating with k=2.6 is equal to the assumption of ongoing innovation.



Scaling Up & Down & Down & Up

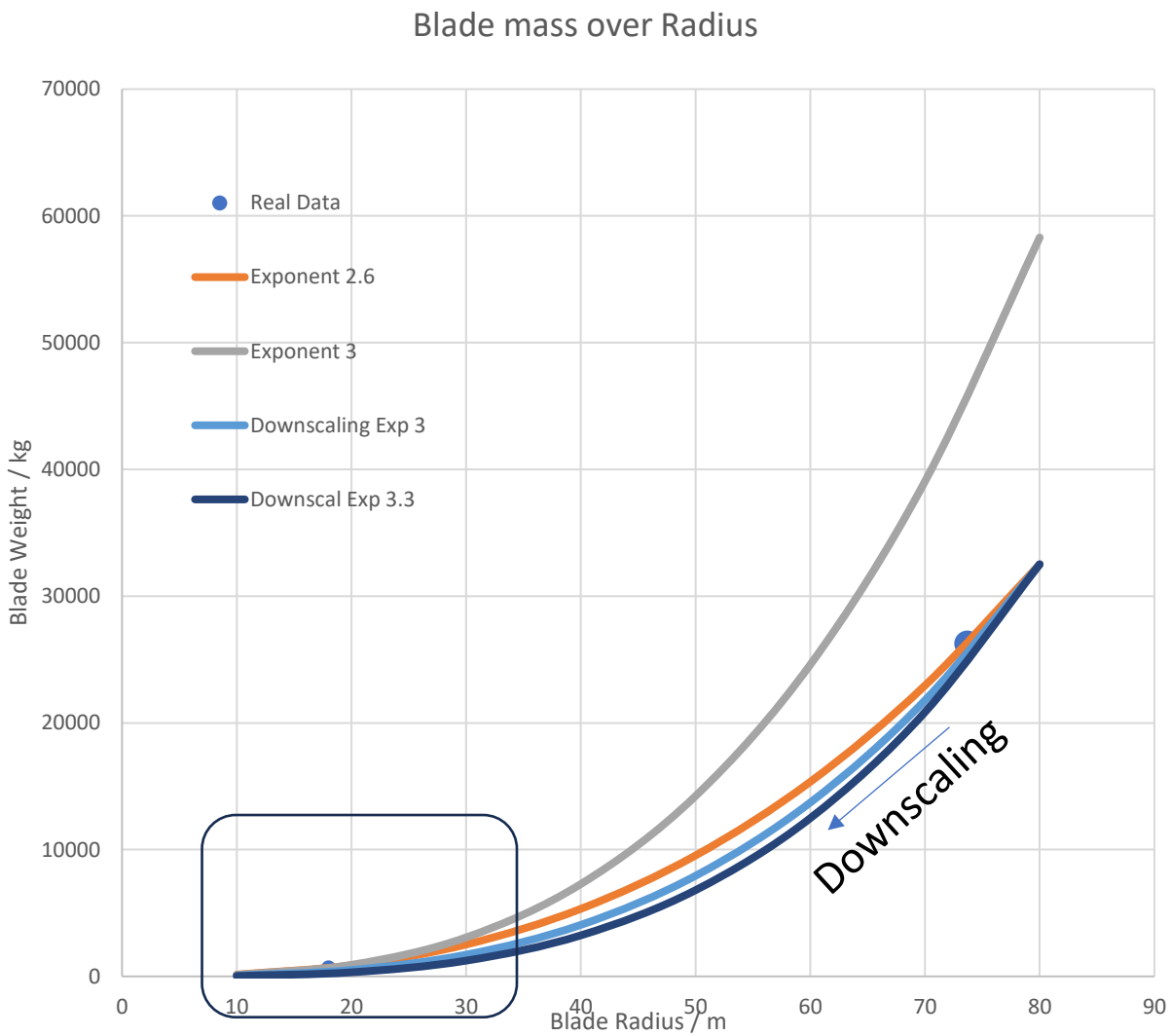
- Downscaling with k=2.6 is traveling back in time. I.e. reverse innovations and learnings.

- Downscaling with k=3 is in line with square-cube law.
  These downscaled blades will be lighter than predecessors, since they make use of 40 years in evolution.



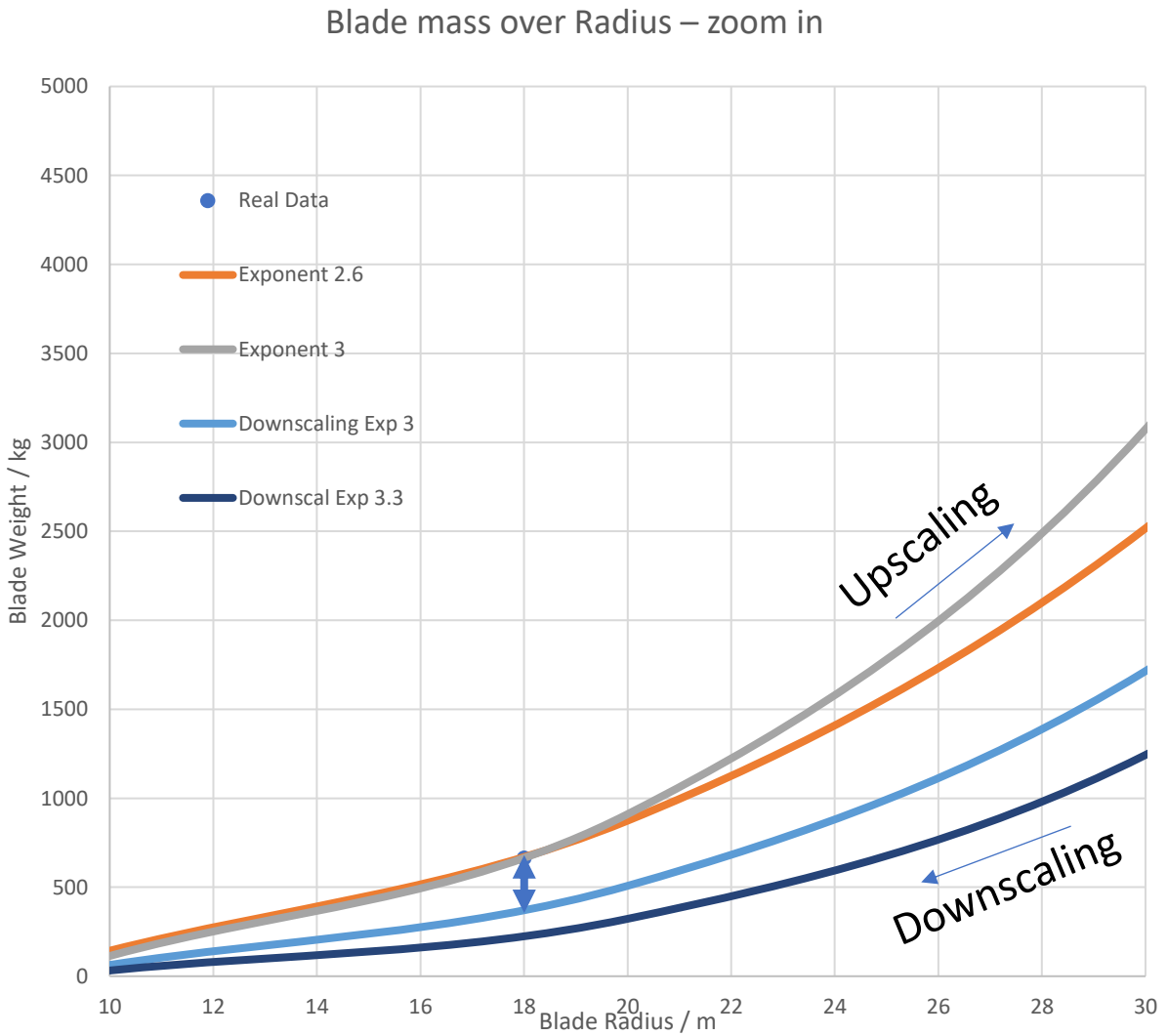
Scaling Up & Down & Down & Up

- Downscaling with k > 3, e.g. 3.3, when applying the physics of scaling and additional learning curves in downscaling.



Scaling Up & Down & Down & Up

- Downscaling with exponent 3 will lead to lighter blades than their predecessors of 40 years ago.
- When applying scaling rules, **differences in up- and downscaling shall be considered.**
- The far better way is to design an MRS-specific rotor-nacelle-assembly from scratch with emphasis on
  - Reliability
  - Sustainability
  - Fit for purpose (e.g., offshore floating might be different than onshore)



Rotor Interaction Blockage Effect

Cp increases with number of rotors

- Blockage effect for Multi rotors increases aerodynamic efficiency $\mathbf{c_p}$, proven with LIDAR measurements and CFD simulations.
- Effect getting bigger with smaller tip clearance and higher number of rotors**.

MRS cp gains vs SR	0,025D tip-to-tip clearance	0,05D tip-to-tip clearance
7 rotors	-	2.55%
45 rotors	8%	7.93%

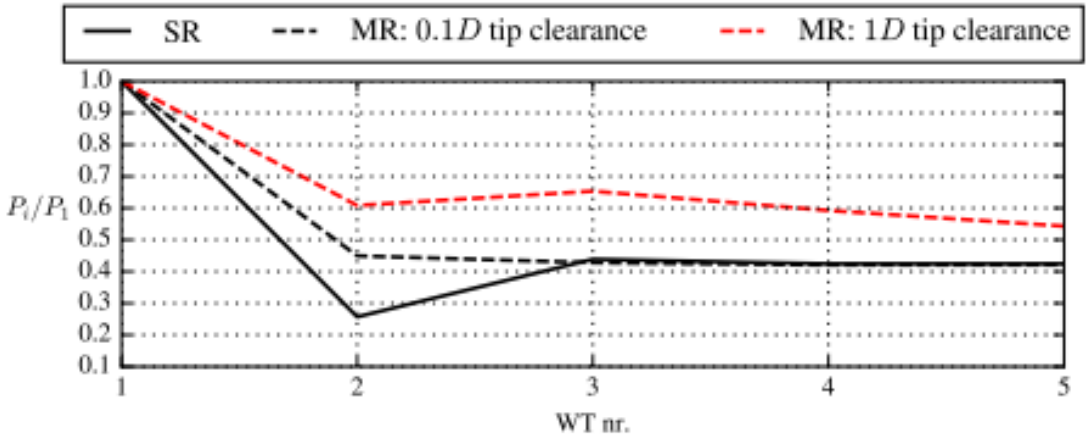
- $\mathbf{c_t}$ values increase approximately the same as $\mathbf{c_p}$

***P Jamieson, M Branney and K Hart (University of Strathclyde), P K Chaviaropoulos and G Sieros (CRES), S Voutsinas, P Chasapogiannis, J M Prospathopoulos (National Technical University of Athens): „Innovative Turbine Concepts – Multi-Rotor System “, Deliverable 1.33, Innwind, September 2015

Wake effects in MRS wind farms

Second row – more wind

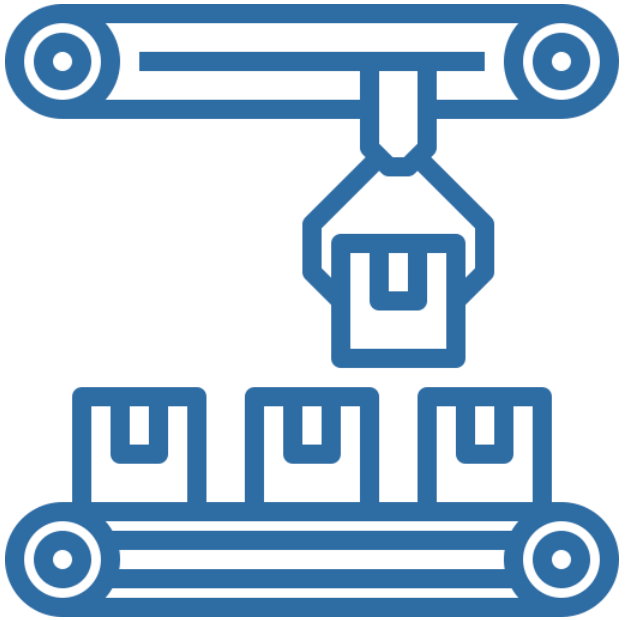
- Wake effects for MRS measured and simulated in various studies [*van der Laan et al; Bastankhah et al; Ghaisas et al] with different methods (LES, RANS, LIDAR measurements) and different configurations (variations in rotor number, gap between rotors, downstream distance, wind and wind direction distribution)
- All studies conclude **improved wake recovery for MRS, particularly for second row**
- Van der Laan concludes **0.3% to 0.7% AEP gain for a 4x4 wind farm** with 5D spacing and uniform wind direction distribution and RANS solver



*M. P. van der Laan and M. Abkar:"Improved energy production of multi-rotor wind Farms", Wake Conference 2019, IOP Conf. Series: Journal of Physics

Economies of Scale (EoS)

How increasing production numbers reduce cost?



- Standardization,
- improved purchasing power,
- automization,
- process optimization leading to

Economies of scale effect*:

$$P_n = P_1 * n_{unit}^{\frac{\ln T_f}{\ln 2}}$$

P_n = cost of the n-th unit [€]
P_1 = cost of the first unit [€]
n_{unit} = number of the unit
T_f = technology factor

- T_f = 0,85 (large EoS-effect) to 0.95 (small EoS-effect)
- Increase of produced units/a from 1,000 to 47,000 → 25 % cost reduction with modest T_f = 0,95

*Hau, Windkraftanlagen, Springer-Verlag

Weight MRS vs SR

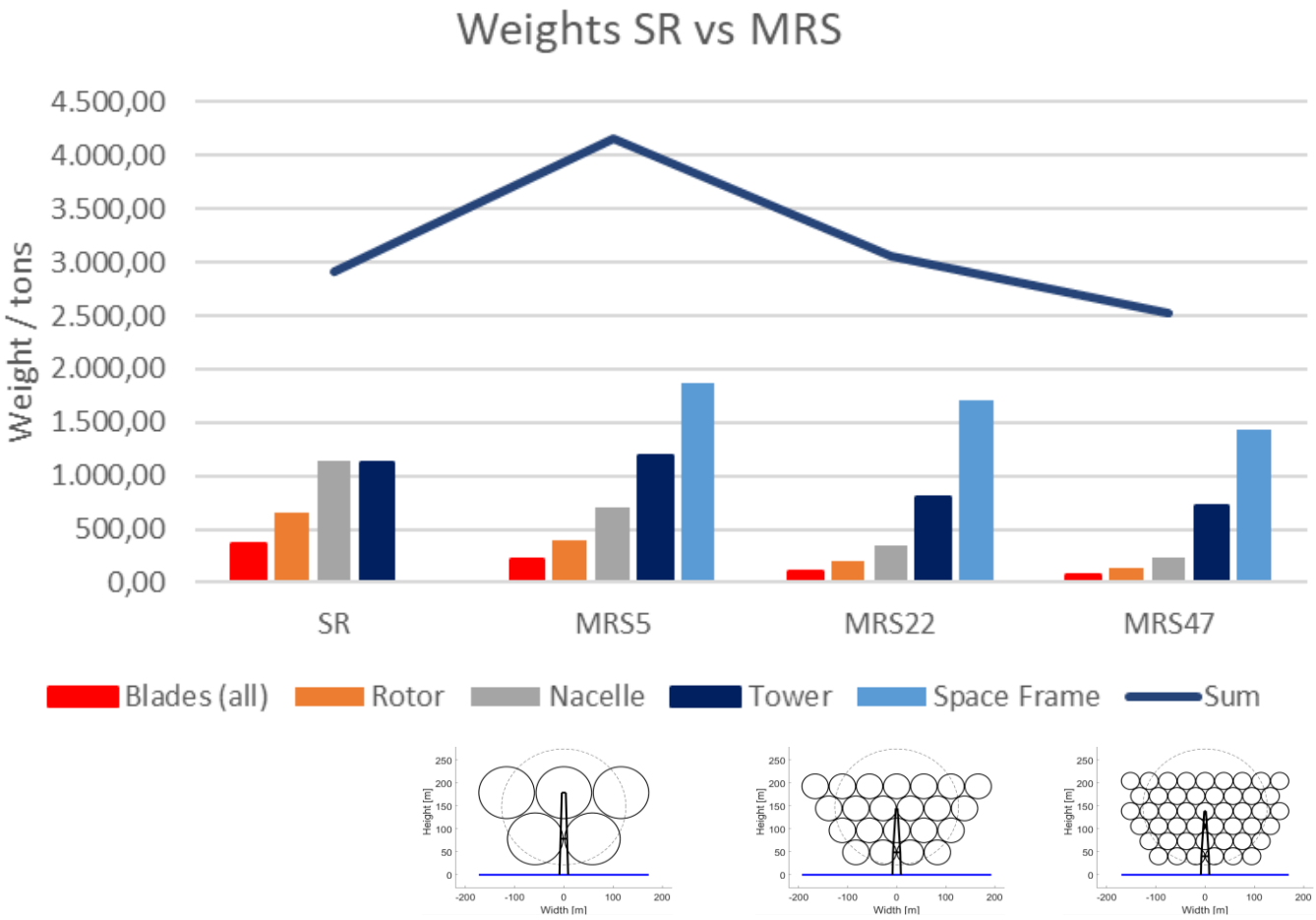
Base Case Results

- MRS substantial weight reduction in RNAs
- Overall weight for MRS47 is lower than SR

Sum of blade weights of MRS47 make only 21% of the SR blade weights.

→ Reduction of non-recyclable materials.

→ Increased use of steel is low price and 100% recyclable.



Conclusion

- MRS benefit from
  - ✓ Economies of Scale,
  - ✓ Scaling Laws,
  - ✓ Improved wake recovery and
  - ✓ c_p-increase by blockage effect, …
- > 40 MW MRS possible without touching physical limits → more efficient land use and less wake effects
- Sustainable by reduction of problematic material volume in RNA, steel space frame fully recycable

Research Needs

Loads & Control

Sustainability

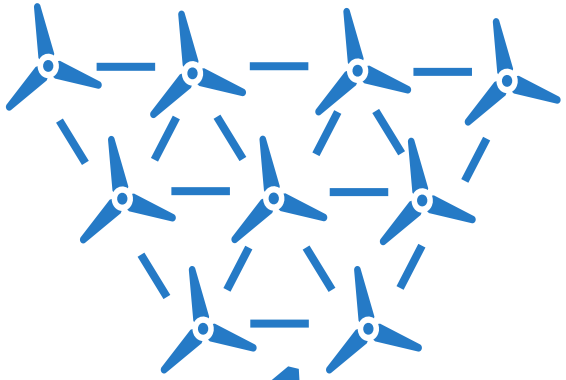
Structure

Mass manufacturing

Floating

Rotor-Rotor-, Rotor-structure interaction

Virtual Research Multirotor



Safety

Wake recovery

Related Technologies

Blockage Effect

Installation

Logistics

Multirotor

O & M

LCoE

Power electronics

Some Knowledge Available

More Research Needed

Thank you and have a nice conference!

Peter Dalhoff

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Thank you.

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