# WP1B4 Up-scaling

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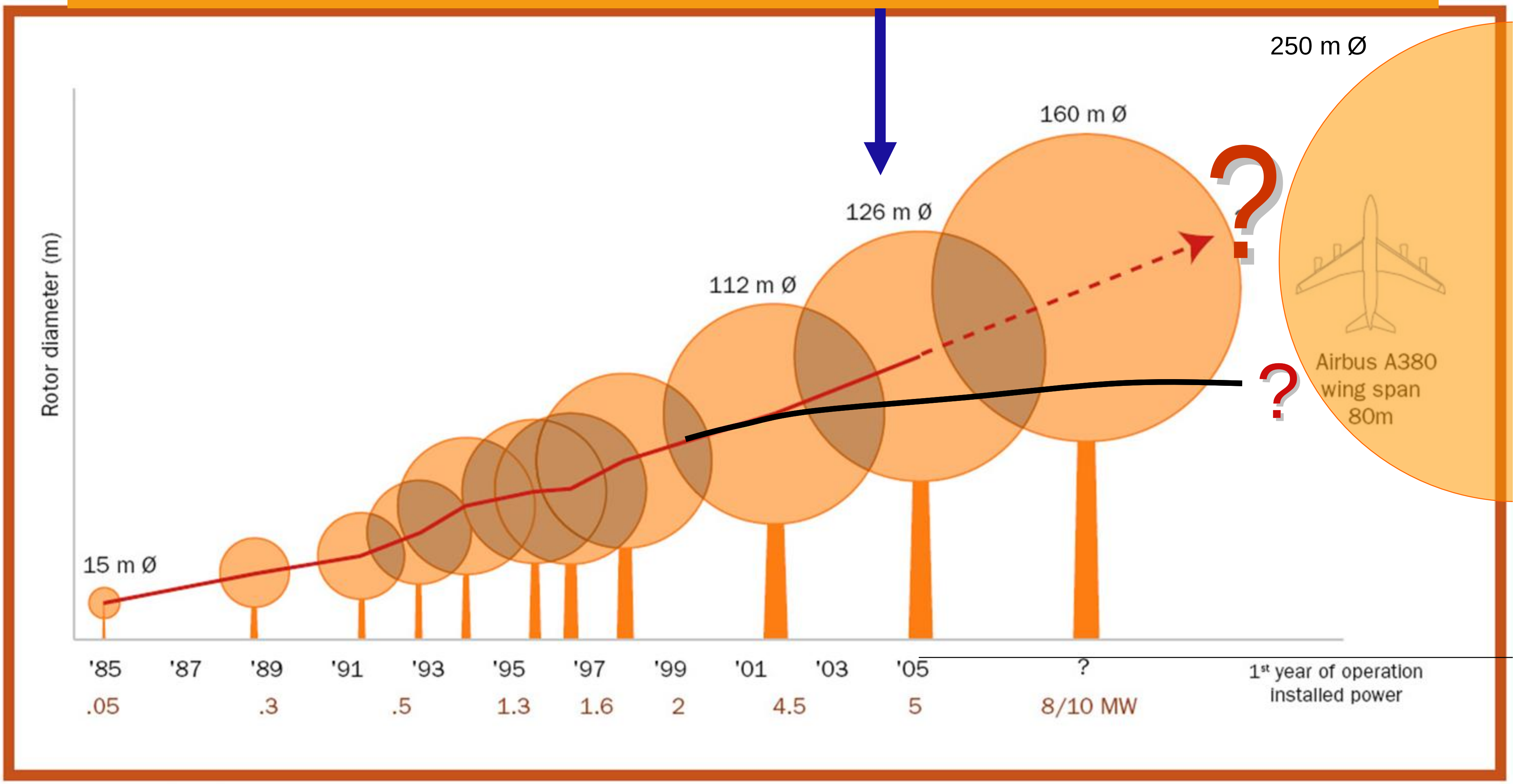
UpWind

# UPSCALE
# The historic growth



# UPSCALE
# a 20 MW turbine in 2020?

a view beyond the present horizon

- *Economy of scale* leads to larger offshore machines:
  - **Which barriers will be limiting**?
- The size and concept of future turbines determines present R&D needs:
  - **Which R&D activities are needed to overcome the barriers?**

# CONTENTS

- Is a 20 MW wind turbine feasible?
- Cost of energy analysis
- Vision on future

# Not feasible?

20 MW turbines are technically not feasible:

- The turbines cannot be **manufactured**; technical barriers prevent the manufacturing of cast steel hubs or bearings
- The turbines cannot be **transported**
- The turbines cannot be **installed**

# Not feasible?

- …we were able to build this in 1889 …

# Not feasible?

- …we were able to build and transport this some decades ago …

Ballast Nedam

Confederation bridge, Canada,

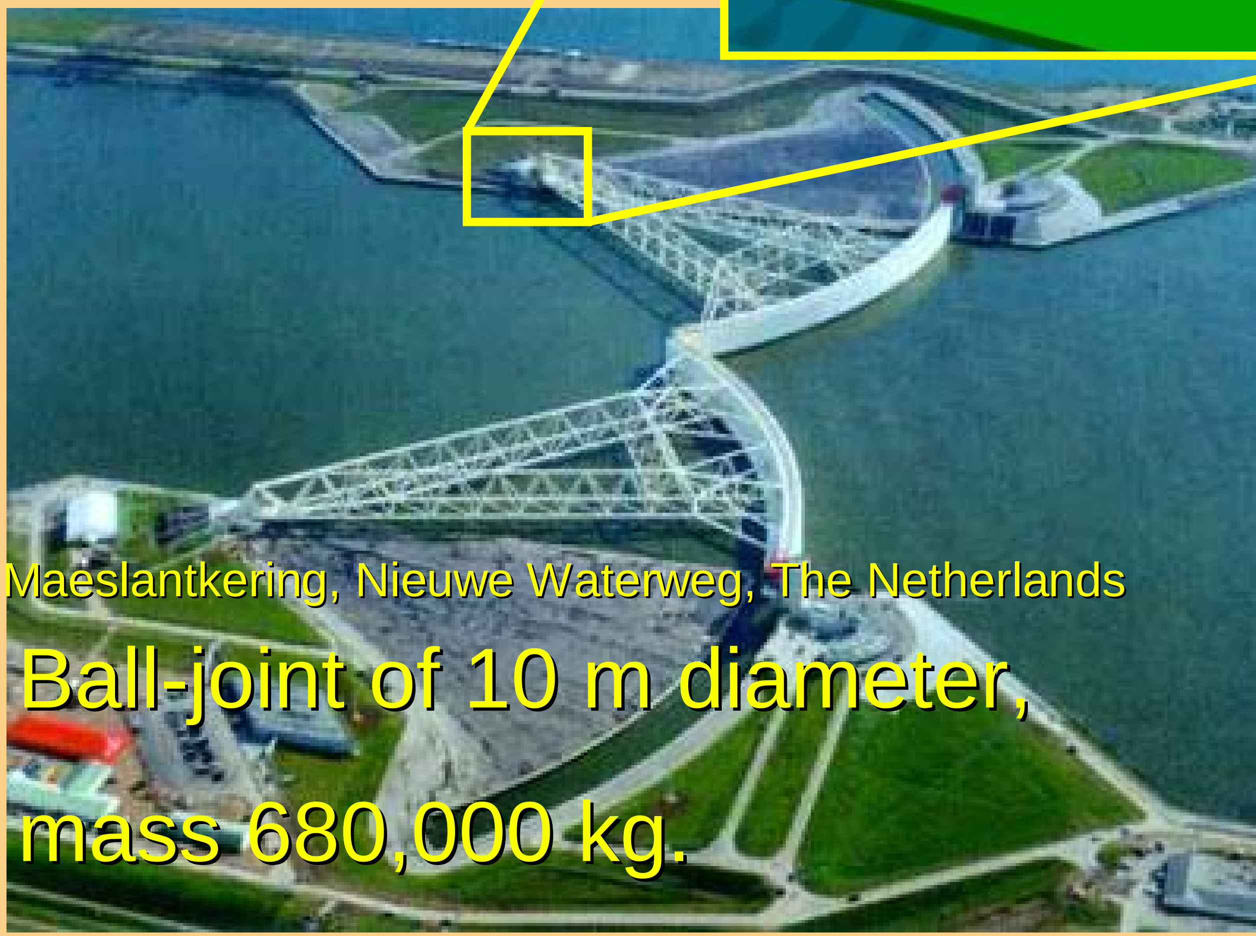
175 elements,

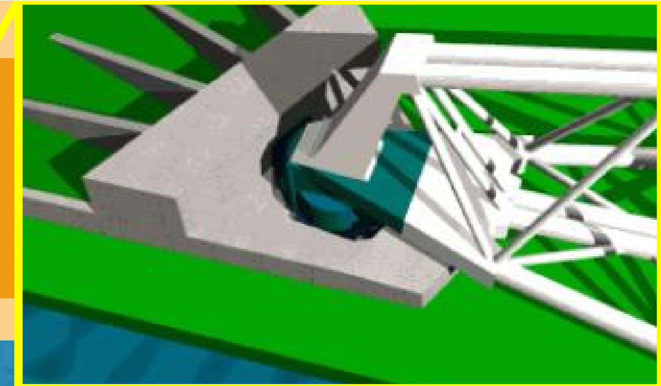
ranging in mass from

1,200 to 7,500 tonnes

# Not feasible?

- …we were able to design and manufacture this some years ago …





Maeslantkering, Nieuwe Waterweg, The Netherlands

Ball-joint of 10 m diameter,

mass 680,000 kg.

# Not feasible??

- …we were able to design and manufacture this some years ago …

# Not feasible?

- So can we build a 20 MW turbine?

# So, what is determining the erection of 20 MW turbines?

**It's the Economy, stupid!**

# Economy of large offshore wind farms

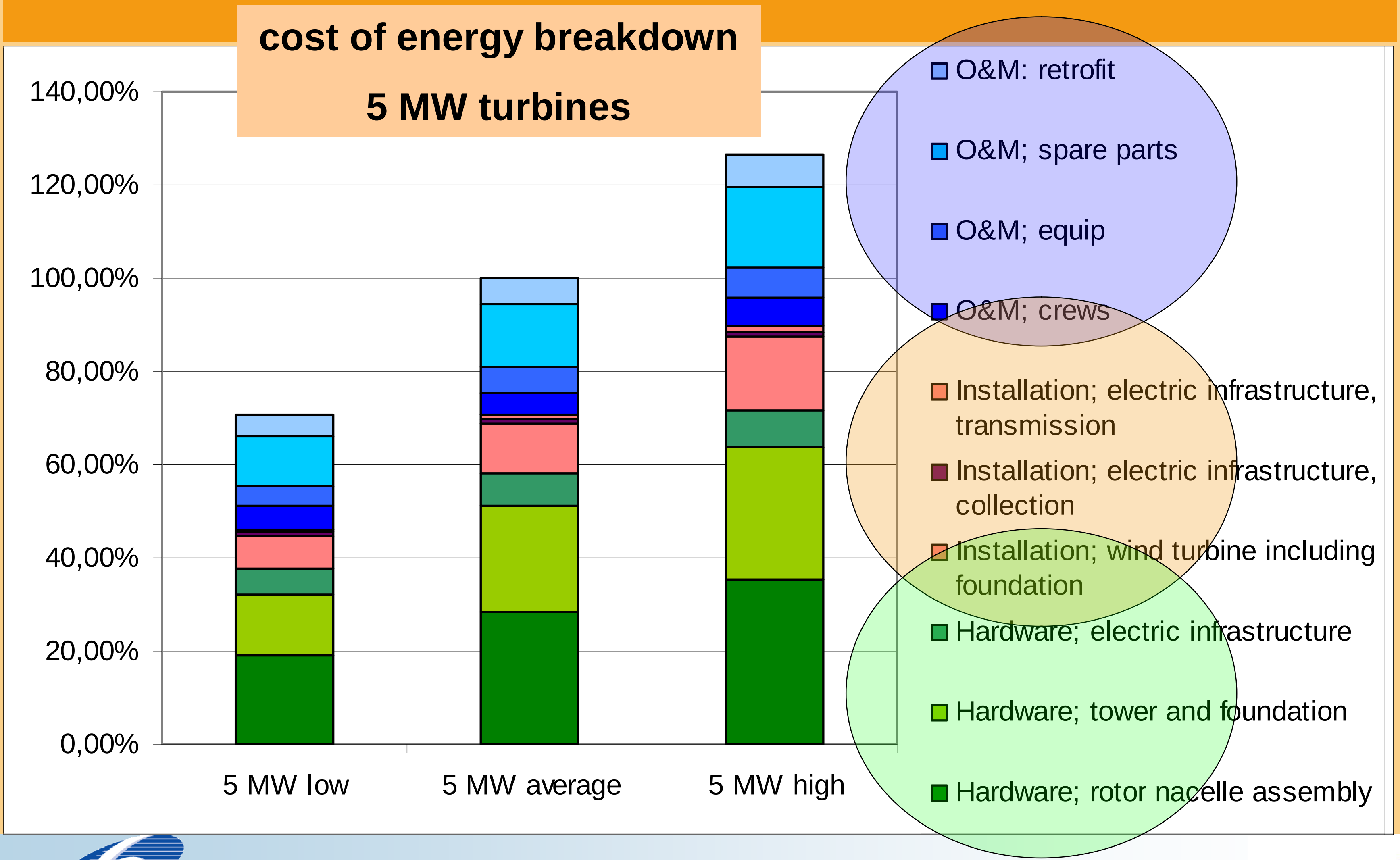
Reference wind farm in our study:

- 500 MW
- 25 km offshore
- 7 diameter spacing
- Present onshore concept and failure rate

External conditions

- IEC Ib wind conditions
- Water depth 30 m
- Northsea wave conditions

# Economy of large offshore wind farms

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# Economy of large offshore wind farms

## Upscaling (from 5 to 20 MW):

- Classical similarity rules
- Beyond classical similarity rules
- Trend data
- Engineering judgment

# Economy of large offshore wind farms

Similarity rules

(Takis Chaviaropoulos)

*2.4. Blade structural properties*

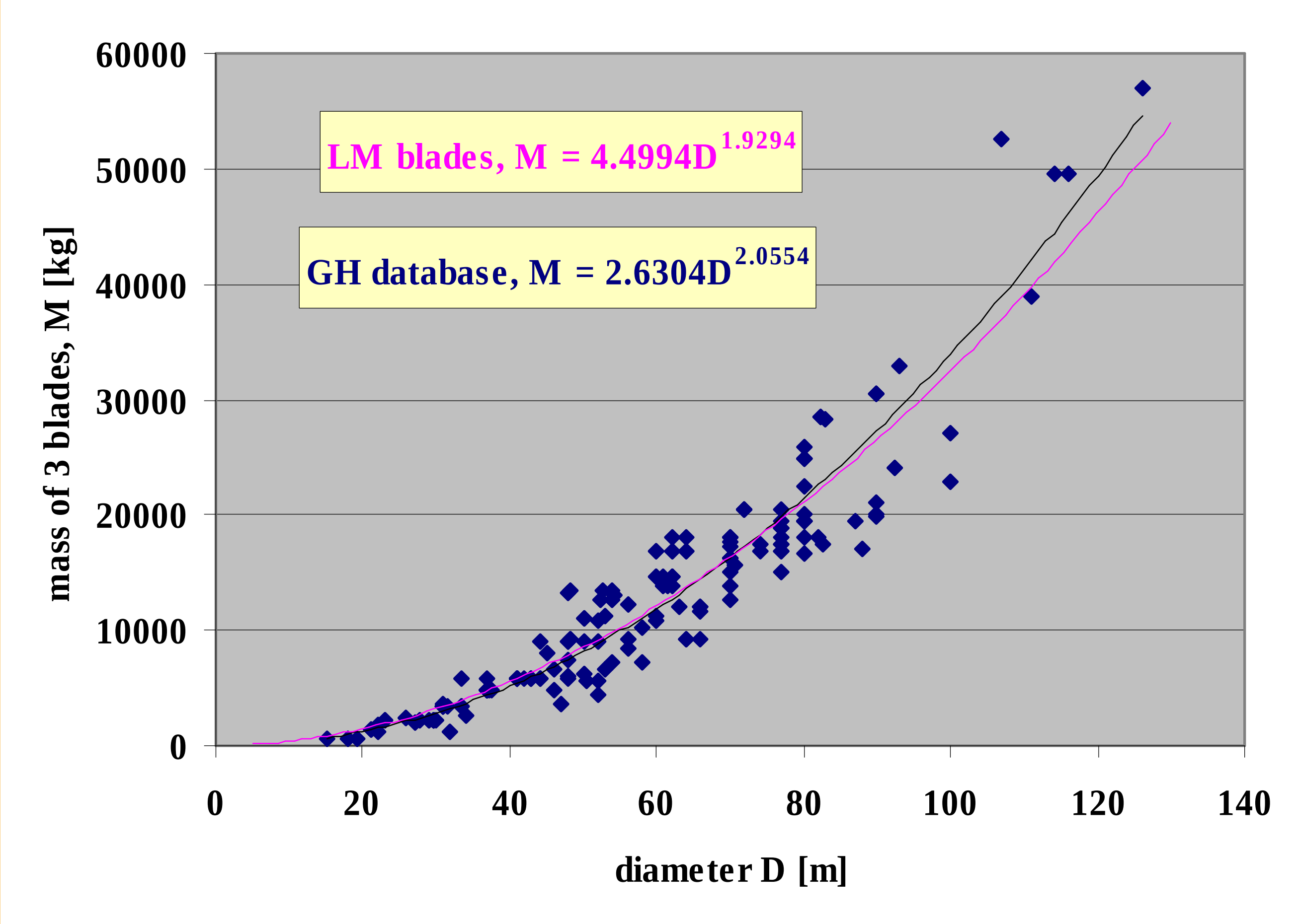
Assuming the geometric up-scaling of the internal blade structure (dimensions scale-up with R, increasing proportionally the number of layers of the same material) and ignoring possible second order effects, the following table results for the sectional properties.

| *Symbol* | *Defining Formula* | *Description* | *Size-Dep.* |
|---|---|---|---|
| $A(x)$ | $= R^2 \int ds^* = R^2 . A^*(x)$ | *Effective Area* | $R^2$ |
| $\underset{\approx}{I}(x) = \begin{pmatrix} I_{yy}(x) & I_{yz}(x) \\ I_{zy}(x) & I_{zz}(x) \end{pmatrix}$ | $= R^4 \begin{pmatrix} \int z^{*2} ds^* & -\int y^* z^* ds^* \\ -\int z^* y^* ds^* & \int y^{*2} ds^* \end{pmatrix}$ $= R^4 . \underset{\approx}{I}^*(x)$ | *Moments of Inertia - Tensor* | $R^4$ |
| $I_p(x)$ | $= R^4 . I_p^*(x)$ | *Polar Moment of Inertia* | $R^4$ |
| $J(x)$ | $= R^4 . J^*(x)$ | *Torsion Constant* | $R^4$ |
| $W_y(x)$ | | *Section Moduli – Y Bending* | $R^3$ |
| $W_z(x)$ | | *Section Moduli* | $R^3$ |

# Economy of large offshore wind farms

Trend data

(Peter Jamieson, Garrad Hassan)

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# Economy of large offshore wind farms

## Upscaling, preliminary results for the blades:

- Classical similarity rules : mass of blade ~ $R^3$
- Beyond classical similarity rules : mass of blade ~ $R^{2.86}$
- Trend data : mass of blade ~ $R^{2.0}$

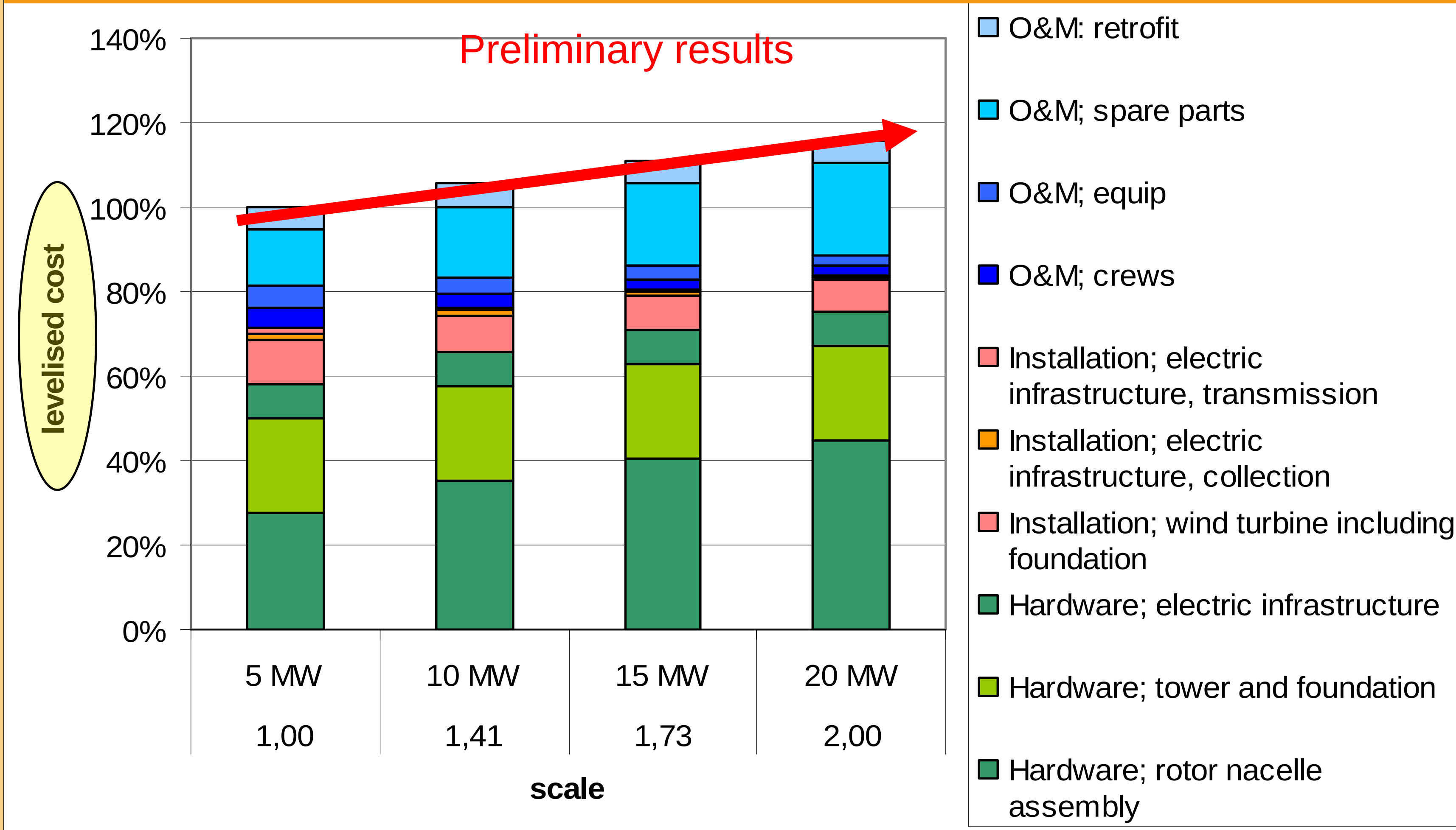
- Further analysis needed to enhance model and to identify the learning curve contribution in the trend data
- The scaling exponent for blade costs will be less then the exponent for the mass of the blade

# Economy of large offshore wind farms

## Upscaling, preliminary results for Cost of Energy

- The scaling exponent for costs is less then the exponent for the mass
- O&M costs for crew, spare parts, vessels, cranes, revenu losses, etc all vary with different scales
- Installation costs vary with less $R^2$

# Economy of large offshore wind farms

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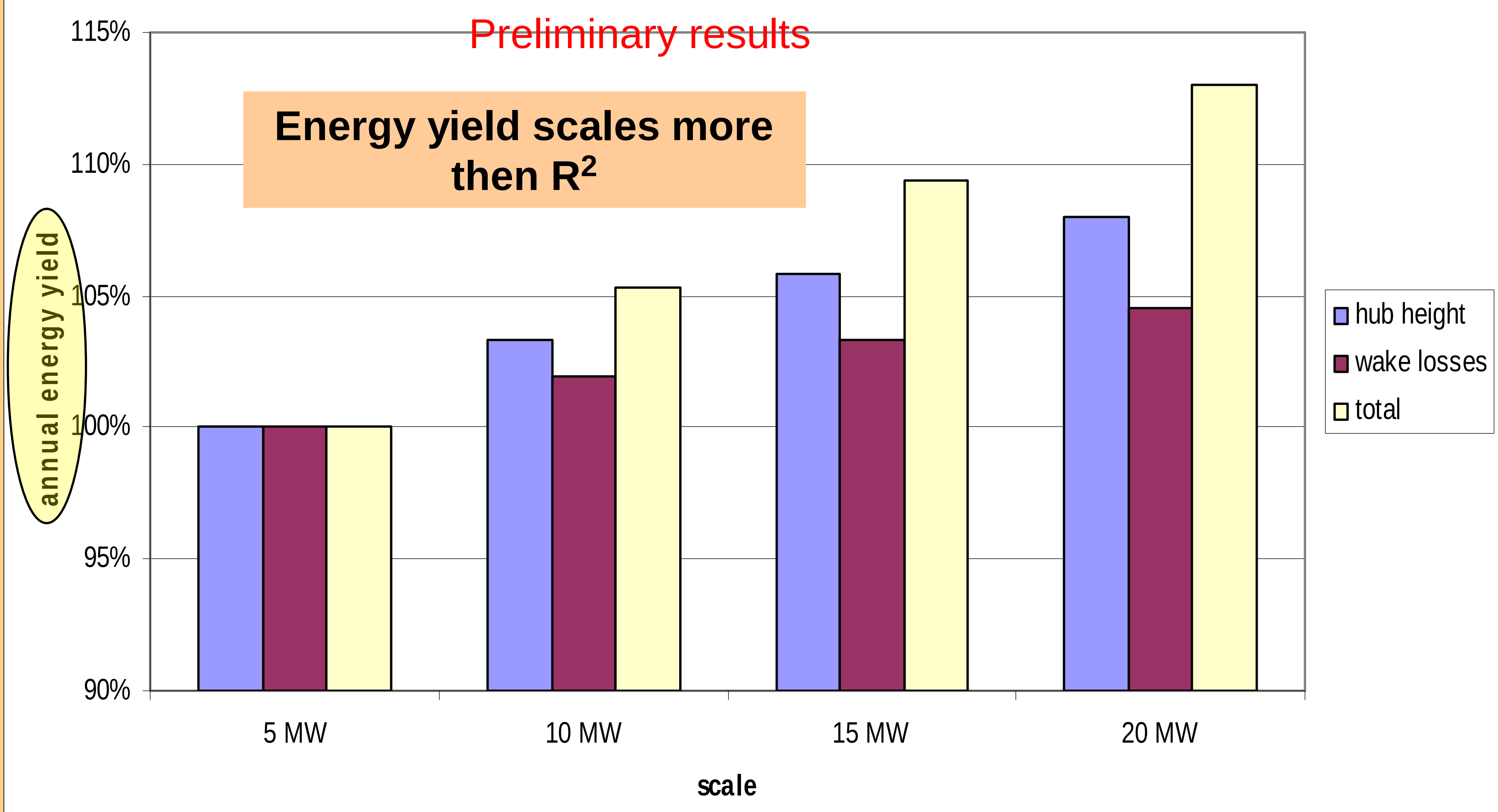
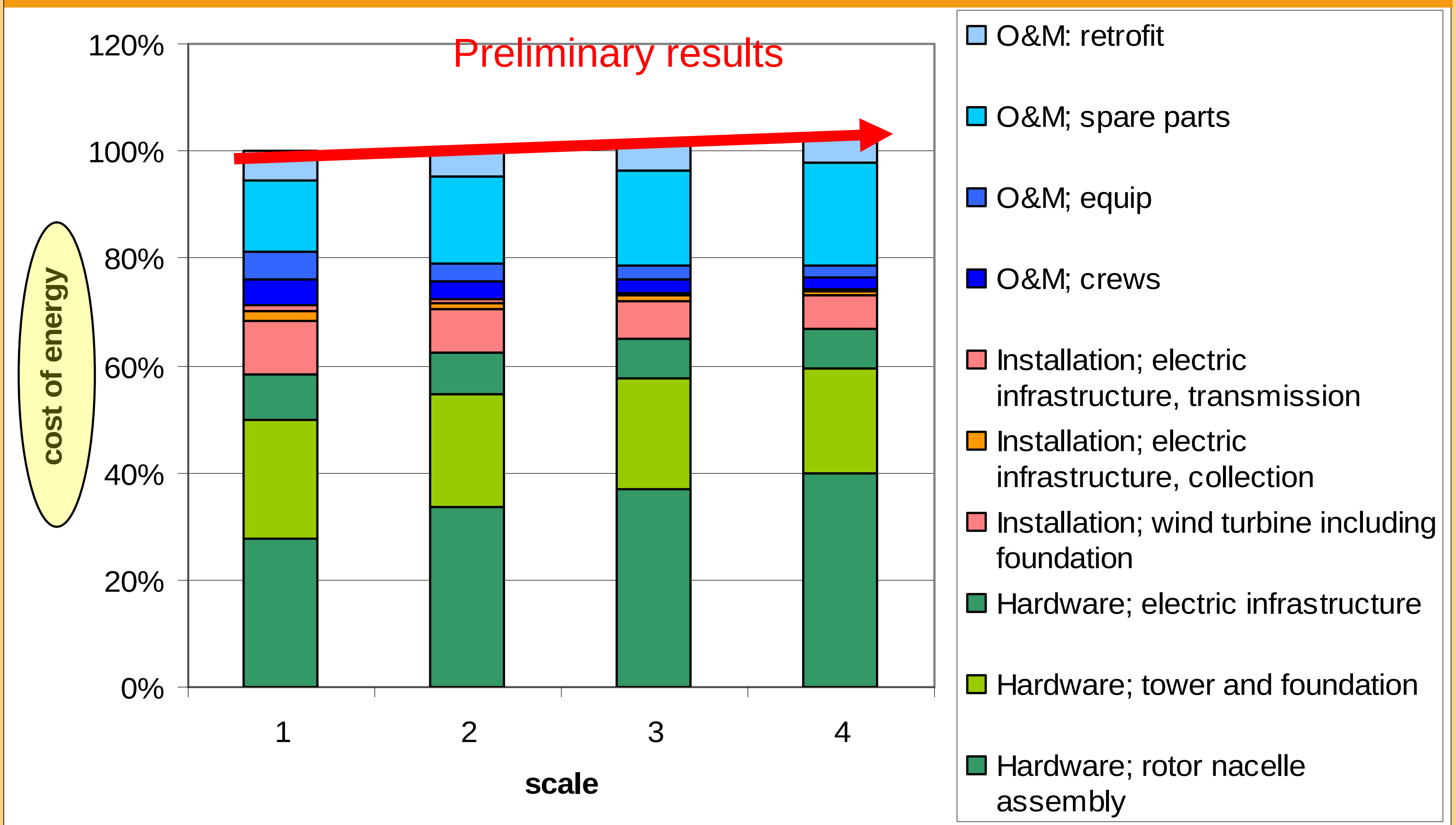
# Economy of large offshore wind farms



# Economy of large offshore wind farms



# Economy of large offshore wind farms

## Upscaling:

- Costs still need to go down…

# Economy of large offshore wind farms

- **Model uncertainties**:
  - Costs and yield are site dependent
  - The characteristics of the reference wind farm are uncertain
  - The scaling rules are uncertain
  - The learning curve, and the introduction of new technologies and new concepts will bring the costs down

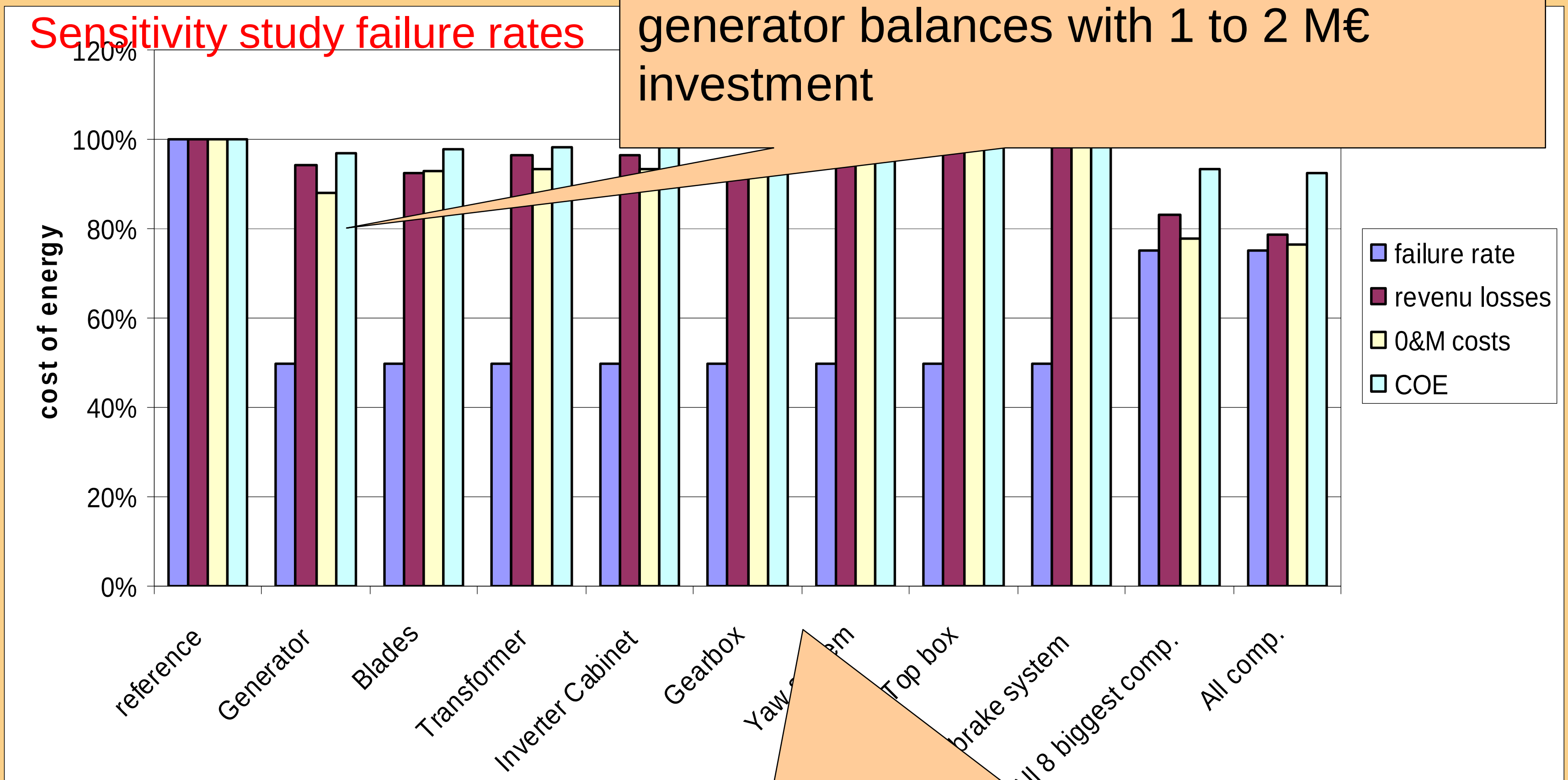
# Economy of large offshore wind farms

- **the ongoing sensitivity study** (reference is **bold**):
  - External conditions
    - wind speed +10%
    - distance to shore **25 km**, 100 km
  - Farm size (**500 MW**, 1000 MW)
  - The most uncertain parameters will be varied
    - Failure rates of all components (75%, **100% reference**, 125%)
    - Waiting days
  - Different scaling exponents
    - Hardware costs scaling exponent (2.3, **2.5,** 2.7)
    - O&M spare parts costs scaling exponent (1.0, **2.0**, 2.7)
    - Offshore crane ships/jack-ups/ scaling exponent: (1.0, 1.5, 2.2)

# Economy of large offshore wind farms

- **the ongoing sensitivity study, improved technology (advanced control, materials, concepts, etc)**
    - Blade material: blades ..% lower costs?
    - Advanced control: 20% lower mechanical loading > 10% lower costs for blades, tower and foundation?
    - Condition monitoring: hardware costs for O&M at 50%
    - Reliable design: balance of investments costs with 50% lower failure rates. Individual components at 50% failure rate, separate analysis per component variation.
    - Flow: ..% lower wake losses
    - Transmission and conversion (Drive train): …
    - Rotor aerodynamics: ..% increased Cp
    - Electrical grid: ..%
    - Characteristics of conceptual changes??

# Economy of large offshore wind farms




50% of the failure rate of the 20 MW generator balances with 1 to 2 M€ investment

50% of the failure rate of the entire 20 MW drive train and power conversion balances with 4 to 5 M€ investment

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# Vision

- It is unlikely that upscaling of present wind turbine designs is optimal for future offshore wind energy:
  - Different scale
  - Turbine should be optimised as a component of the wind farm
  - Different external conditions

# Vision on future designs

- Design drivers:
  - Design for robustness
  - Design for installation
  - Design for lower mass

# Vision on future designs

- Design drivers:
  - Design for robustness:
    *no pitch and cluster coupled variable speed?*
    *modular design?*
    *commissioning of turbine in harbour?*
    *condition monitoring?*

# Vision on future designs

- Design drivers:
  - Design for installation:

    *2-blades?*

    *shock proof?*

# Vision on future designs

- Design drivers:
  - Design for lower mass:

    *high tip speed?*

    *active boundary layer control?*

    *advanced materials?*

    *Advanced control?*

# Vision on future

- The future design may be uncertain

- It is certain however that **major R&D and industrial effort with large financial investments will be needed** to conquer all technical barriers!