RAMBØLL

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AWESOME
PhD'S IN WIND POWER O&M

The decision on the time to switch from lifetime extension to repowering

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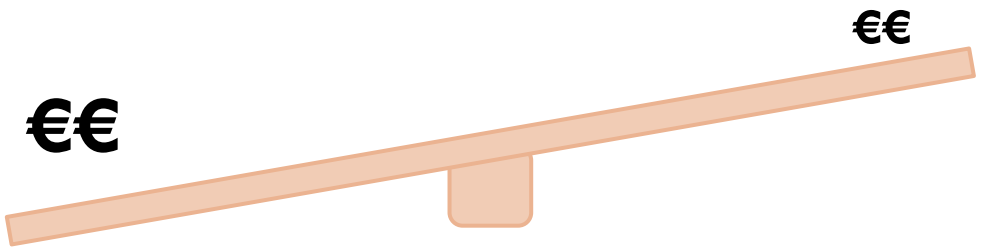
Lifetime extension if…

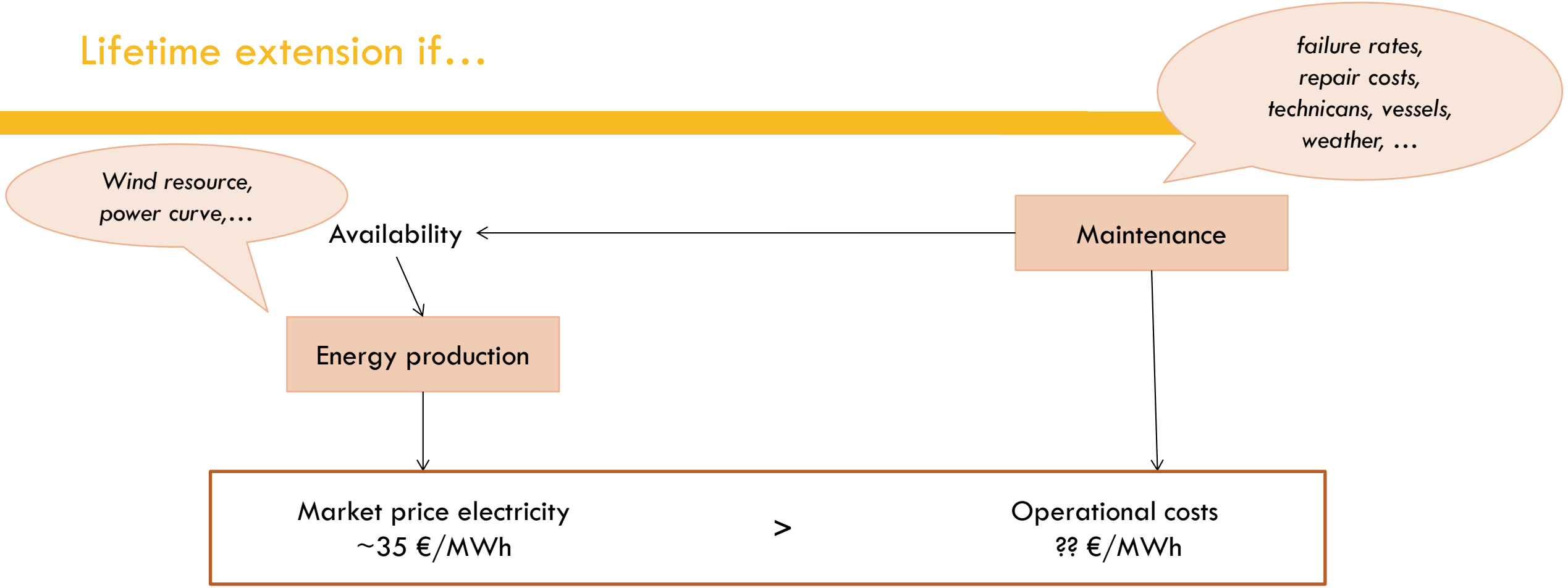


Market price electricity ~35 €/MWh	>	Operational costs ?? €/MWh

Simple question - but how to do it?

Lifetime extension if…

Lifetime extension if…



The better the data basis – the better the decision!

Step 1: Start with a simple decision model

- Deterministic model based on expected values (averages)
- Optimisation of length of lifetime extension
- Objective function = maximise capital value

- Applicable
  - when you are certain about your input
  - for large asset numbers

Case study
Offshore wind farm
Old: 100 turbines 3MW
New: 60 turbines 6MW

Maintenance model - simplified

Item	Unit	Value	Source
Scheduled maintenance	[€/year]	95 000	[1]
Transport costs	[€/failure]	15 000	[2]
Labor costs (3 technicians)	[€/h]	300	[2]
Major replacement	[€/failure]	50 000	[3]
Major repair	[€/failure]	10 000	[3]
Minor repair	[€/failure]	5 000	[3]
Repair time	[h/failure]	12	[3]
Repair delay time	[h/failure]	48	[2]

- Simplified maintenance model
- Can be linked to full maintenance tool if available
  - Maintenance scheduling
  - Vessel and technician availability

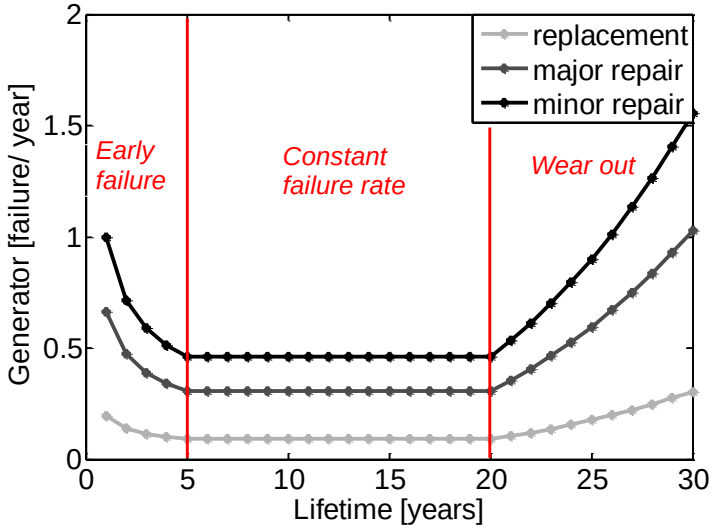
Maintenance model - simplified

- Failure rates [3]
  - Major replacement, major repair, minor repair, no cost
  - Wear out components
  - Constant failure rate components
- Wear out and remaining useful lifetime
  1. Data driven
     - Own data? Extrapolation?
     - Reference data?
  2. Physics driven
     - Physical models
     - Monitoring and inspections

Wear out	Constant
Pitch/ hydraulic	Electrical
Other components	Circuit breaker
Generator	Controls
Gearbox	Safety
Blades	Sensory
Grease oil/ liquid	Power/ converter
Pumps/ motors	Service item
Hub	
Heaters/ coolers	
Yaw system	
Tower/ foundation	
Transformer	

Maintenance model - simplified

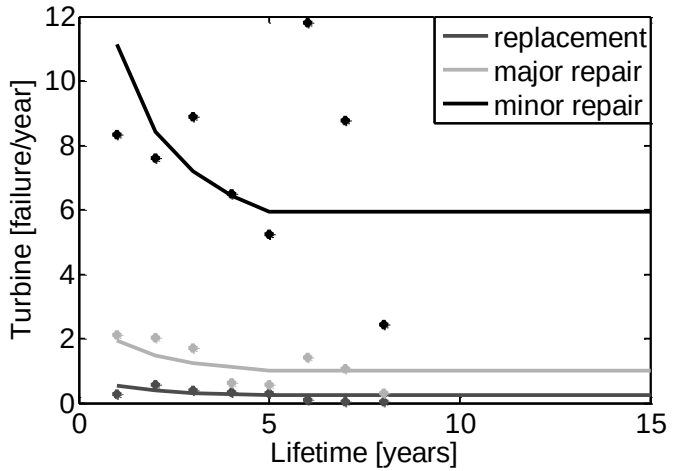
- Bathtub curve
  - Early failures
  - Constant failure rate
  - Wear out



- Fit to 8-year of data [3]
  - Weibull distribution

$$failure\ rate = \lambda\ \beta\ (\lambda\ t)^{\beta-1}$$

λ: shape parameter (data fit)
β: scale parameter (data fit, 1, 4)



Energy production model - simplified

Item	Unit	Value	Source
Energy price life extension	[€/MWh]	40	[4]
Energy price repowering	[€/MWh]	75	[5]
Full load hours	[h/turbine/year]	4500	[6]

- Time-based availability
- Can be linked to full maintenance tool if available
  - Weather simulations
  - Energy-based availability

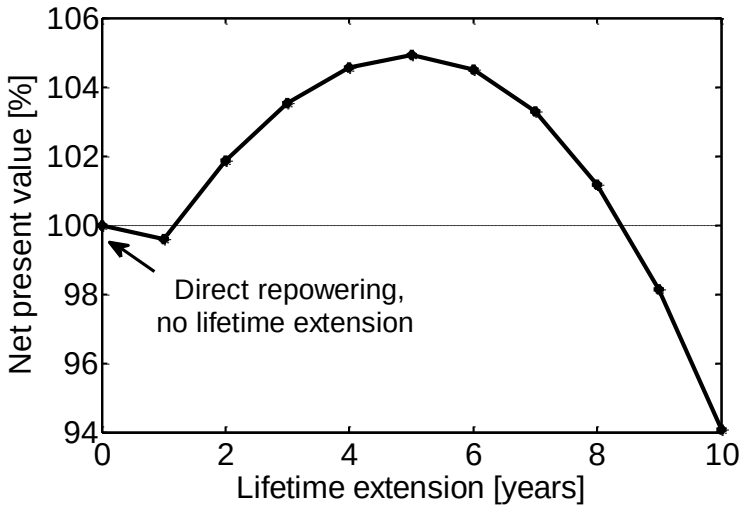
Other inputs

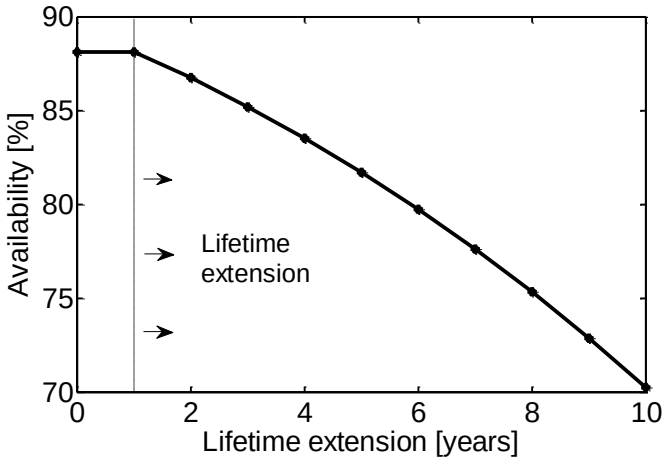
Item	Unit	Value	Source
Life extension assessment	[€/turbine]	25 000	[7]
Retrofit	[€/turbine]	50 000	[7]
Condition monitoring	[€/system]	75 000	[7]
Insurace	[€/MW/year]	15 000	[1]

- Individual life extension assessment for every turbine
- Retrofit for every turbine (e.g. blade exchange, bolt tightening)
- Condition monitoring of 30% of installed turbines

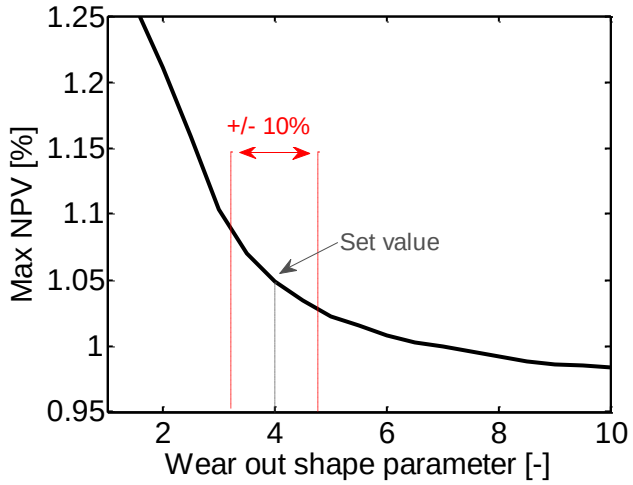
Model results

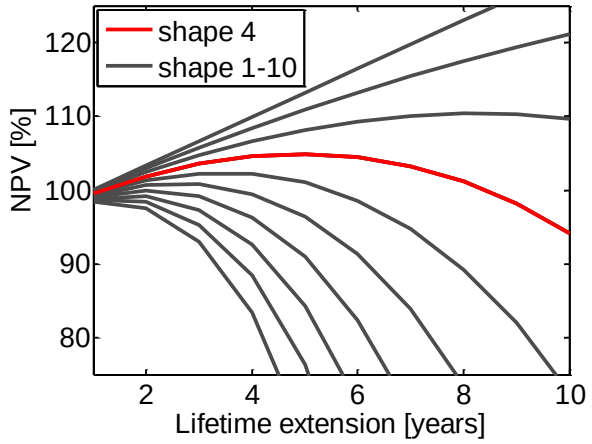
- OPEX-based
- 5 years optimum
- Drop afterwards due to
  - Increase failure rates
  - Increase maintenance costs
  - Decrease availability
  - Decrease revenues

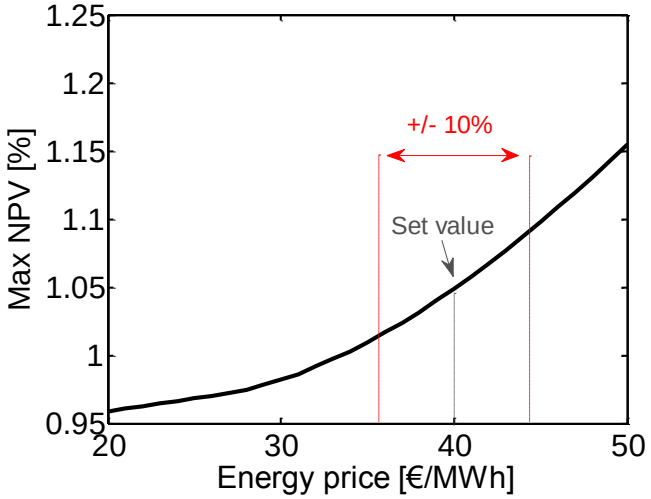


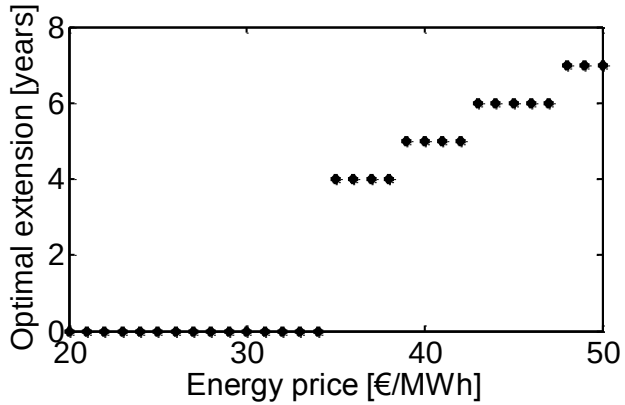


Is the decision sensitive to uncertain assumptions? Yes, it is!



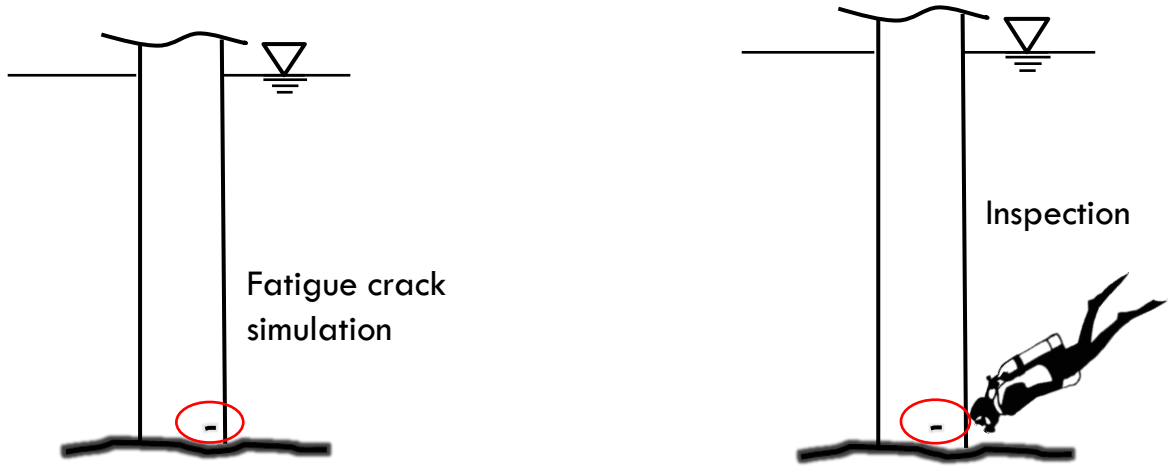






Step 2: Make the model probabilistic

- Scenario analysis
- Bayesian analysis & subjective uncertainties
- Risk-based decision criteria



$$P(C|I) = \frac{P(C) \cdot P\,(I|C)}{P(I)}$$

Conclusion

1. Good knowledge about wear-out and energy prices is crucial for the end-of-life decision.
2. Stochastic methods help to deal with uncertainty.
3. Further low-cost monitoring is needed to decrease risk in decision making.

Future work:

Structural monitoring, probabilistic decision model, …

Thanks for your attention

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Study on lifetime extension – DE, ESP, DK, UK

- Survey within European research project „AWESOME“
- State-of-art, challenges, regulations, decision making
- 30min interview with operators, manufacturers, certifiers, ...

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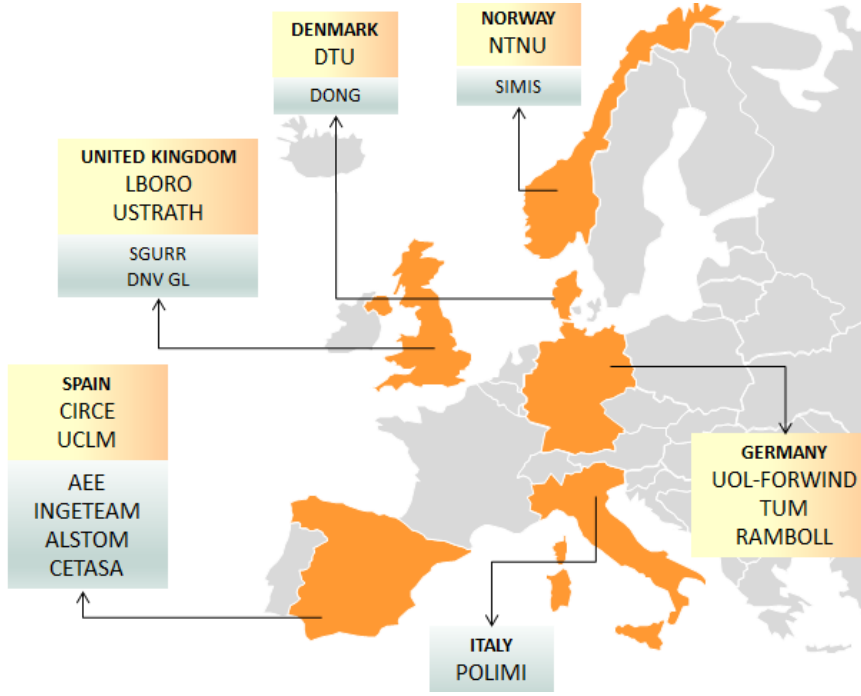
AWESOME

- AWESOME = Advanced wind energy systems operation and maintenance expertise
- Marie Skłodowska-Curie Innovative Training Networks
- 11 PhD's
- O&M
  - Failure diagnostic and prognostic
  - Maintenance scheduling
  - Strategy optimization



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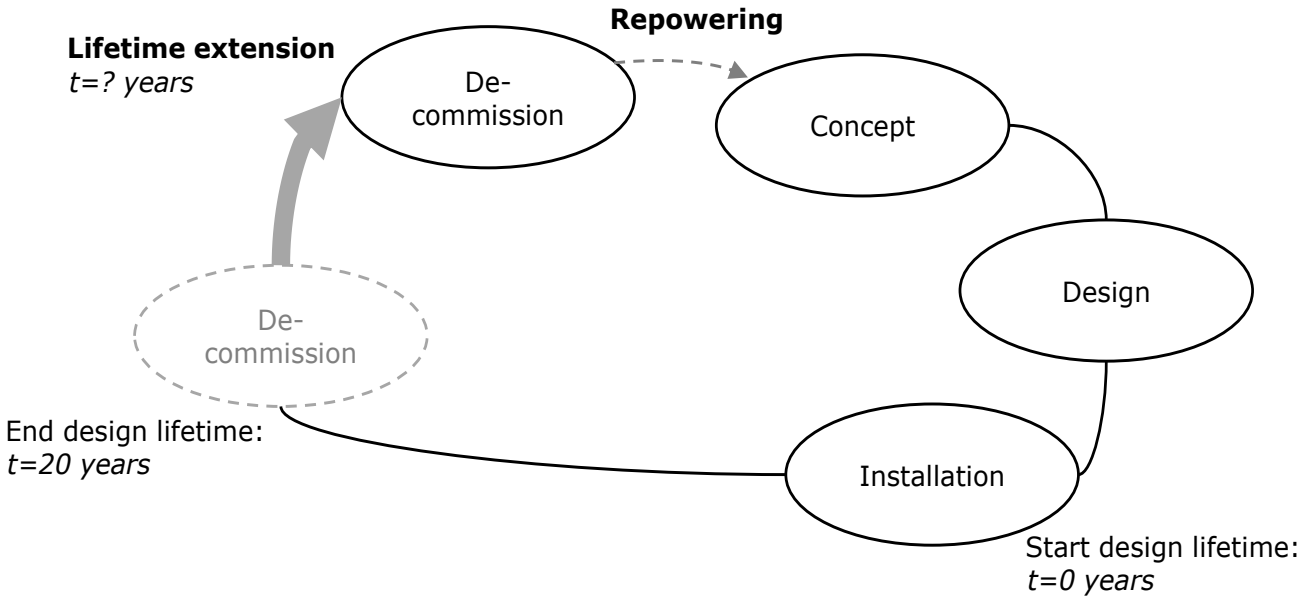
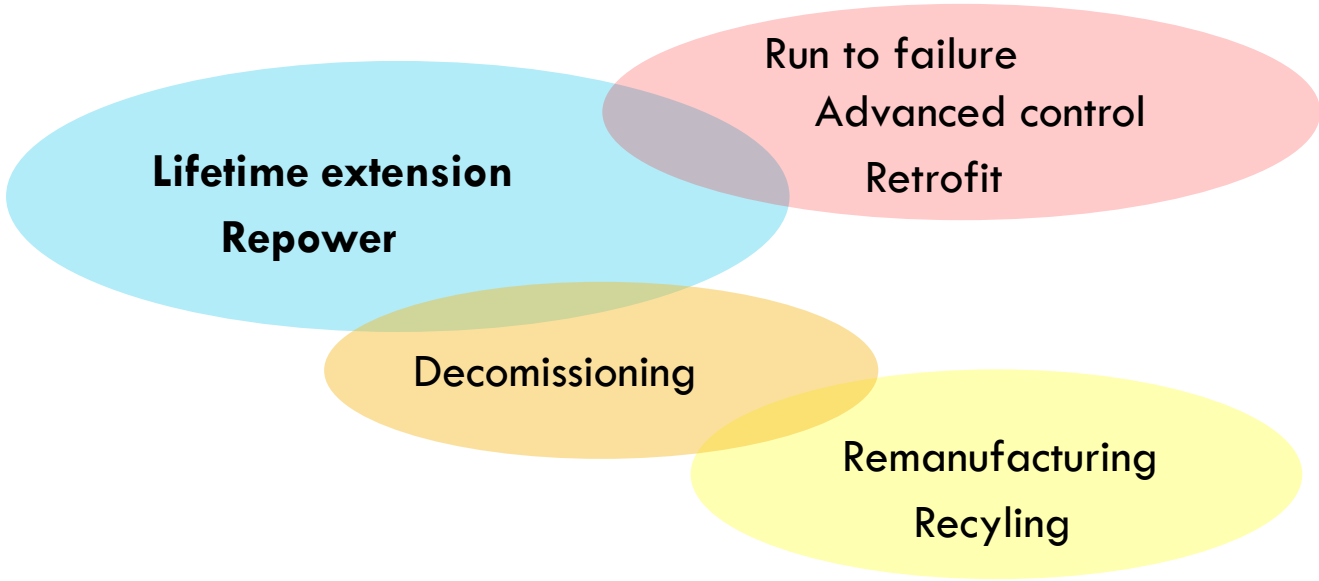
What to do at the end of service life of wind turbines?



The decision is…



- End-of life scenarios
- Decision criteria
- Data basis