ENHANCE DECISION SUPPORT TOOLS THROUGH AN IMPROVED RELIABILITY MODEL

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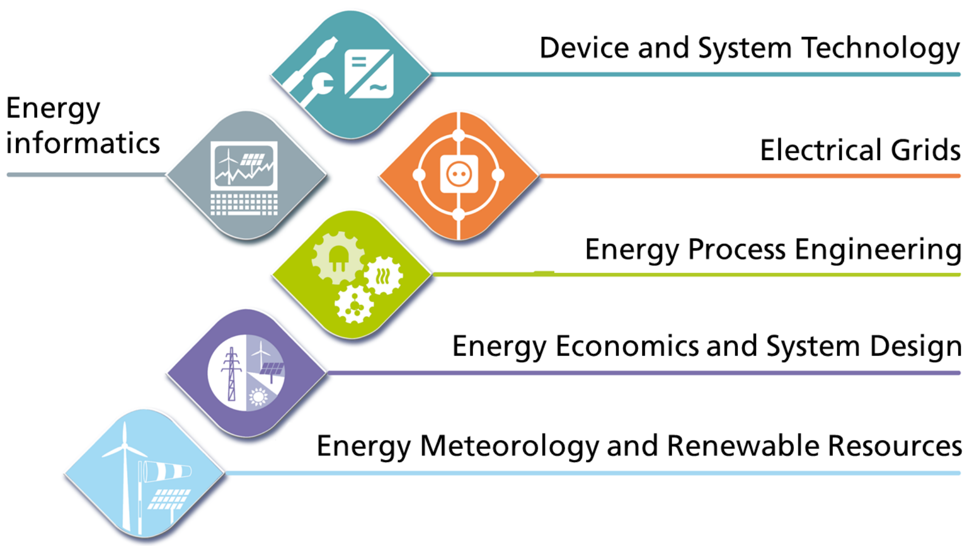
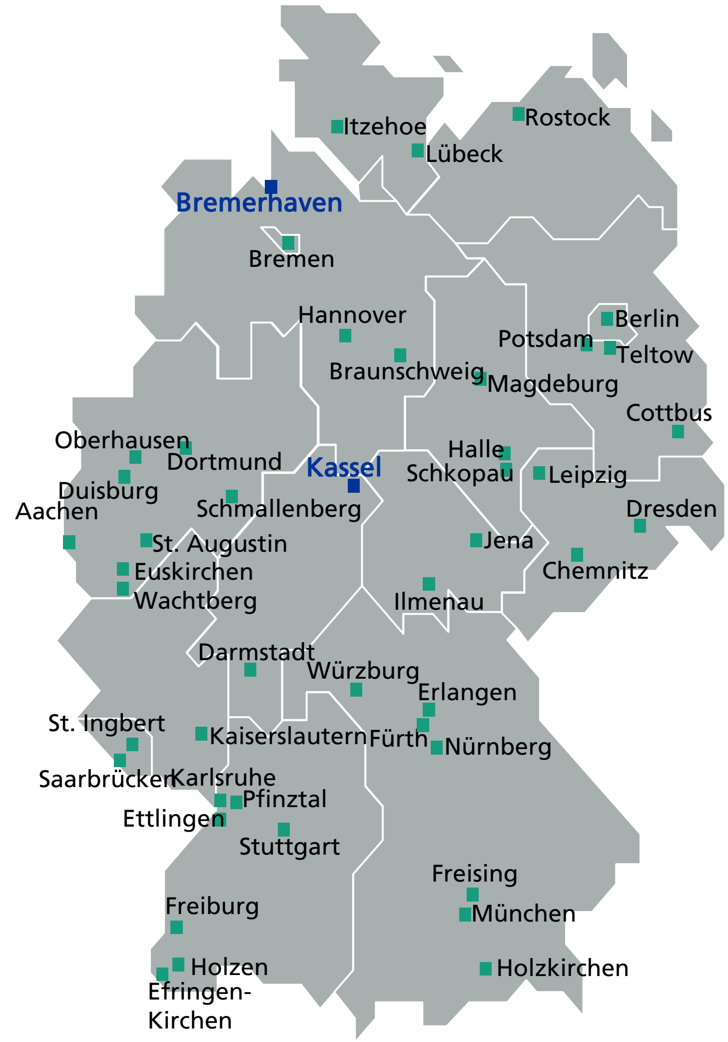
Introduction

Fraunhofer Institute for Wind Energy and Energy System Technology





- Personal: approx. 310
- Annual budget: approx. 20 Mio EUR
- Director: Prof. Dr. Clemens Hoffmann

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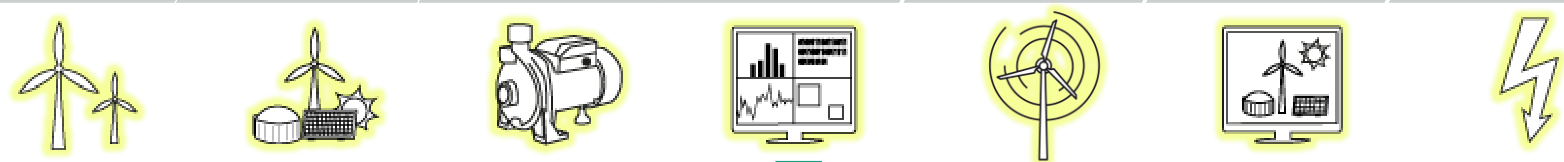
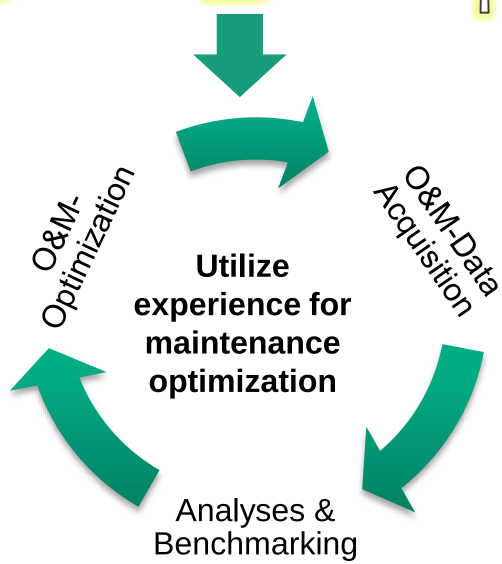
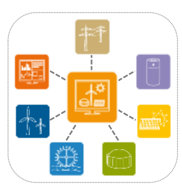
Introduction

Research group „Reliability & Maintenance strategies“

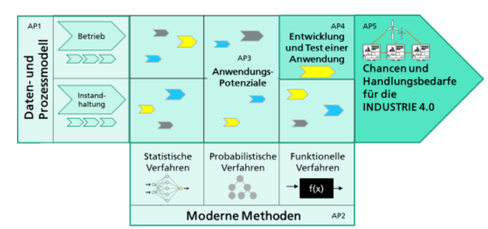
Resources	Planning	Turbine technology	Operation & Maintenance		Grid integration	
Spatial planning	Design of energy supply systems	Optimization of electrical machines	Maintenance optimization	Control concepts	Forecasting	Solutions for grid connections







WIND pool



Decision support tools

Variety of tools

Table 1: Overview of models reviewed

				Project Phase		Aspects Considered									Features							
	Name	Organisation	Year	Construction	Operation	Turbine	Support Structure	Electrical Infrastructure	Transport/ Installation	Weather/ Wind/Waves	Wake	Maintenance Strategy	Failures	Total Project Perspective	Uncertainty	Offshore	Commercial	Simulation/ Optimization	Software	Time Horizon	Model Output	Source
Total Project Cost	Rambølls tool	Rambøll	2003	x	x	x	x	x	x	x		x		x	yes	yes	(yes)	Sim	Excel, RiskSim	Life cycle	Net present value	[14, 15]
Total Project Cost	IEA recomm-endation	IEA	1994	x	x	x	x	x				x		x	yes	no	no	Sim	Excel	Life cycle	Levelized production cost	[16]
Total Project Cost	Extend simulation of DNV	DNV	2010		x	x		x	x	x	x	x	x	x	yes	yes	(yes)	Sim	Extend	Life cycle	Net present value and others	[17] and direct contact
Total Project Cost	Fingersh et al.	NREL	2006	x	x	x	x	x						x	no	yes	no	Sim	Excel	long term	Cost of energy	[18]
Total Project Cost	OFWIC	George Washington University	2010	x	x	x	x	x	x	x	x			x	yes	yes	no	Sim/ Opt	Excel, Palisade, Frontline	Life cycle	Cost of energy	[19, 20]
Operation and Maintenance	RECOFF-model	ECN	2004		x	x			x	x		x	x		yes	yes	no	Sim	Excel, @Risk	long term	Costs	[21]
Operation and Maintenance	ECN O&M Tool	ECN	2007		x	x			x	x		x	x		yes	yes	yes	Sim	Excel, @Risk	long term	Costs	[22]
Operation and Maintenance	OMCE	ECN	2009		x	x			x	x		x	x		?	yes	no	Sim	(MatLab)	long term	Costs	[23]
Operation and Maintenance	CONTO FAX	TU Delft	1997		x	x			x	x		x	x		yes	yes	no	Sim	Excel	long term	Costs, availability, energy produced	[24, 25]
Operation and Maintenance	O2M	Garrad Hassan	2007		x	x			x	x		x	x		no	yes	(yes)	Sim/ Opt	not specified	long term	Costs, lost production	[26]
Operation and Maintenance	MWCOST	BMT	2009	x	x	x	x		x	x		x	x		yes	yes	(yes)	Sim	not specified	long term	Net present value	[27, 28]
Operation and Maintenance	Maros	DNV	2010		x	x		x	x	x		x	x		yes	(yes)	yes	Sim	Own develop-ment	long term	Net present value	[29]

Source: Hofmann. 2011 [1]

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Decision support tools
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- **M**ulti-**A**gent **S**imulation as support for a reliability oriented maintenance of offshore wind farms
- Offshore-TIMES - Offshore Transport, Inspection and Maintenance Software

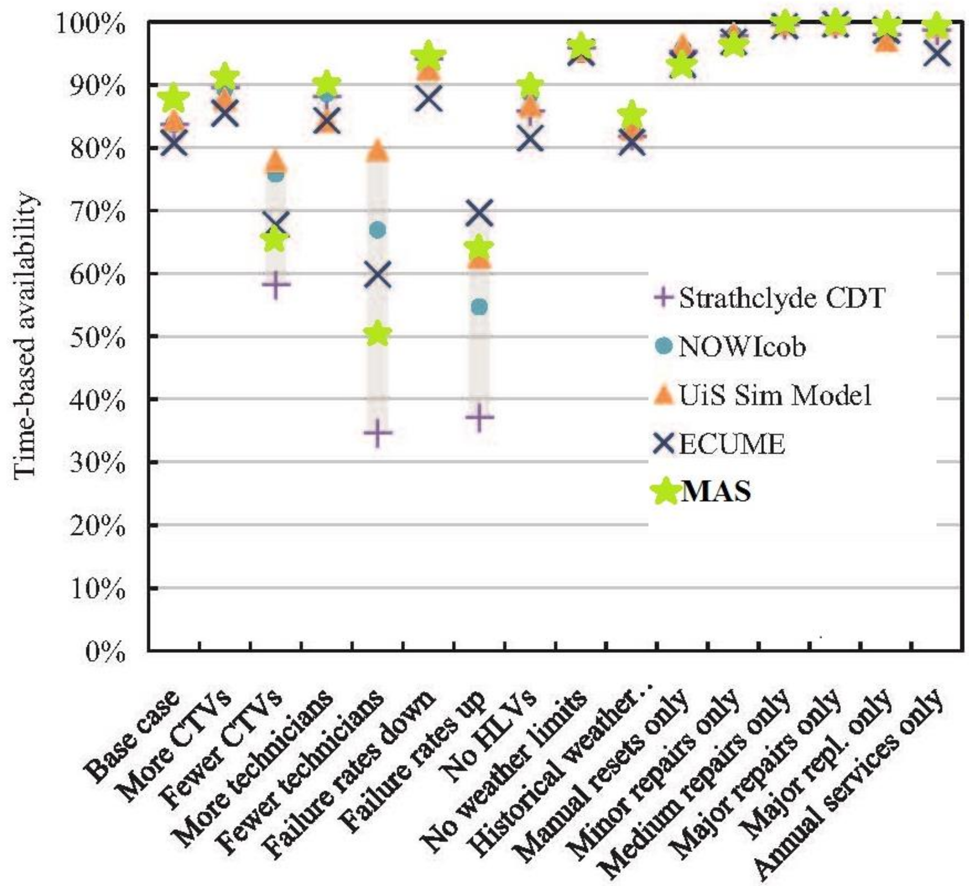


Figure 1. Average value for the time-based availability for the models for the reference cases

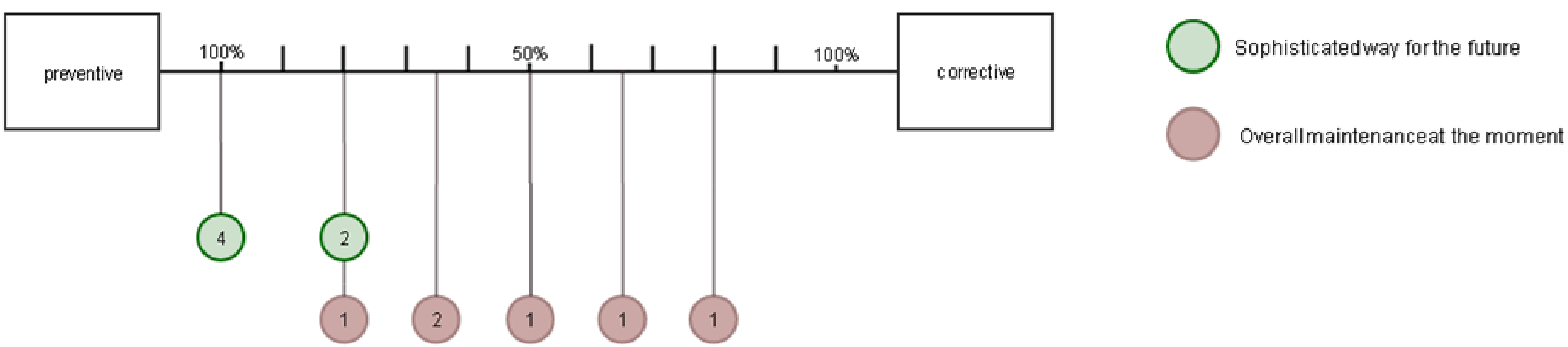
Source: MAS-ZIH, adopted from Dinwoodie 2015 [2]

Reliability model
Requirements

FAILURE INPUT	Manual reset	Minor repair	Medium repair	Major repair	Major replacement	Annual service
Repair time	3 hours	7.5 hours	22 hours	26 hours	52 hours	60 hours
Required technicians	2	2	3	4	5	3
Vessel type	CTV	CTV	CTV	FSV	HLV	CTV
Failure rate	7.5	3.0	0.275	0.04	0.08	1
Repair cost [19]	0	£ 1000	£ 18 500	£ 73 500	£ 334 500	£ 18 500

Source: Dinwoodie 2015 [2]

Stakeholder Workshop



Source: Offshore-TIMES

Reliability model
Requirements

Stakeholder Workshop

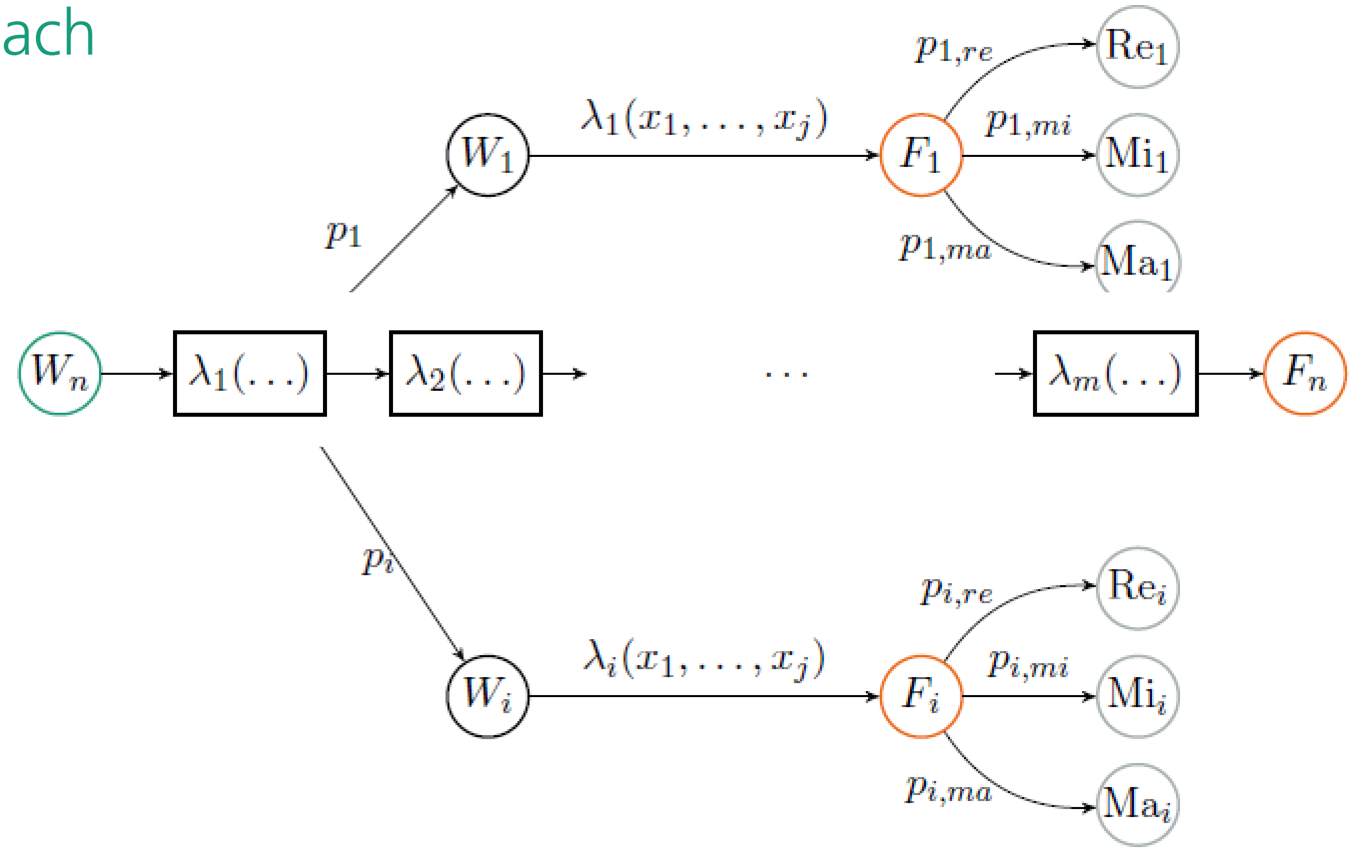
Level of detail

Have the use-case of the simulation in mind.
For strategic purposes the focus should be on the main components.

Influencing parameters

Cluster	Parameter
Time	Age of component
	Time
Stress	Full load hours
	Shear modus
	Deviations
Environment	AMB temperature
	Wind speed
	Wave height
	Wake effect
Maintenance	Crane/non-crane components
	Rate/degree/effort of maintenance
	Human factor

Reliability model
Approach



Share of failure categories

Mathematical description

Failure consequence

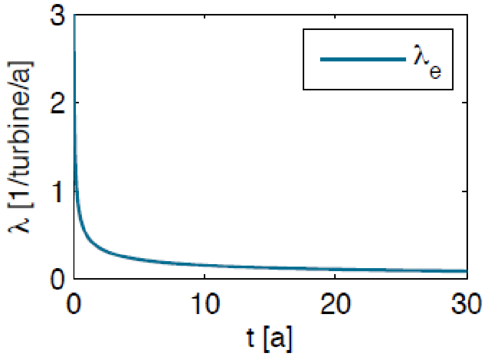
Component reliability

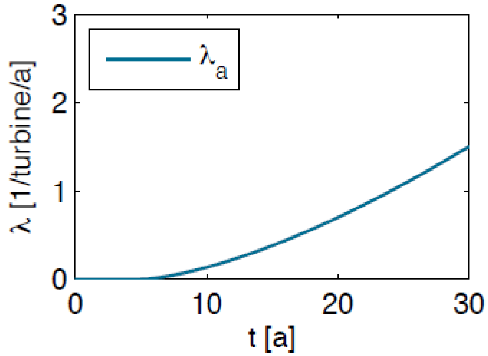
Turbine reliability

Failure categories
Time

- Early failures
- Aging failures

$$f(t) = \begin{cases} 0 & t < 0 \\ \frac{\beta}{\eta}\left(\frac{t - t_0}{\eta}\right)^{\beta - 1} e^{-\left(\frac{t-t_0}{\eta}\right)^{\beta}} & 0 < t < t_{max} \end{cases}$$





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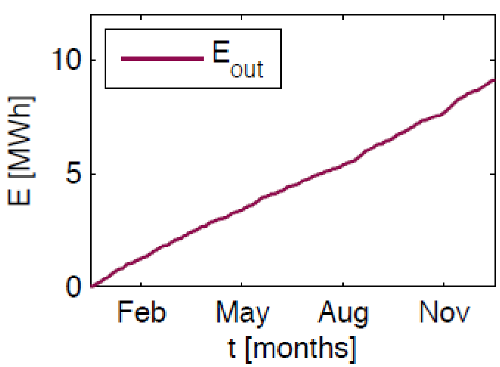
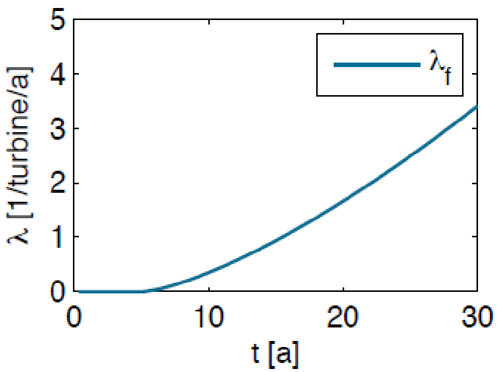
Failure categories
Stress

- Early failures
- Aging failures
- Fatigue failures

$$f(E) = \begin{cases} 0 & E < 0 \\ \frac{\beta}{\eta}\left(\frac{E}{\eta}\right)^{\beta-1} e^{-\left(\frac{E}{\eta}\right)^{\beta}} & E \geq 0 \end{cases}$$





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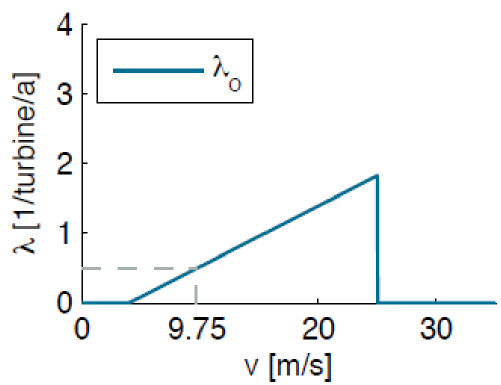
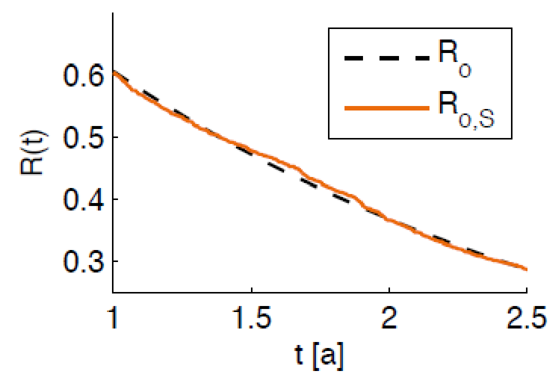
Failure categories
Environment

- Early failures
- Aging failures
- Fatigue failures
- **Overload failures**

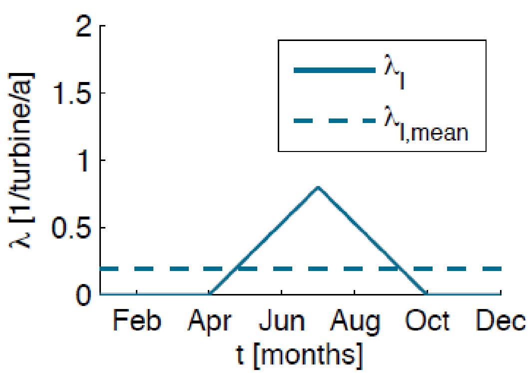
$$\lambda_{overload}(v_{wind}) = \begin{cases} 0 & v < v_{wind} \\ m * (v - v_{wind}) & v_{min} < v < v_{max} \\ 0 & v > v_{max} \end{cases}$$

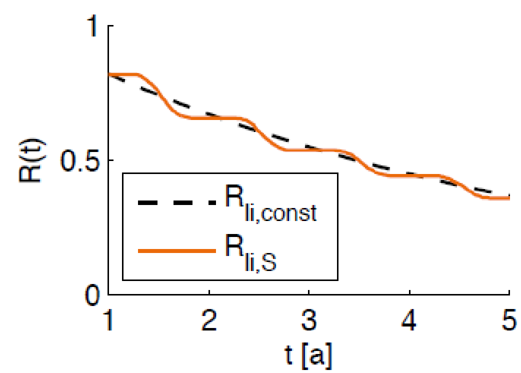




Failure categories
Environment

- Early failures
- Aging failures
- Fatigue failures
- Overload failures
- System-specific failures

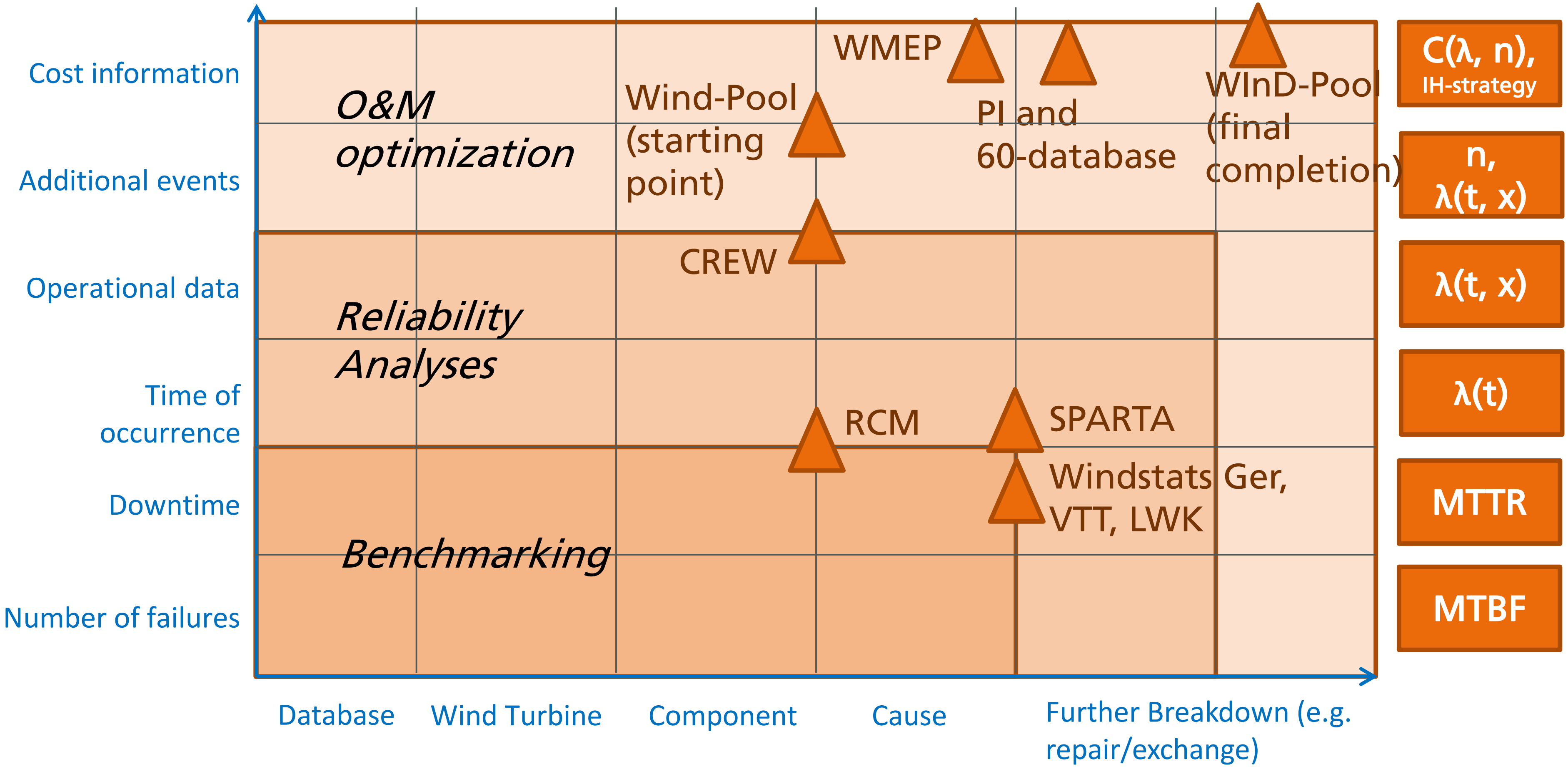




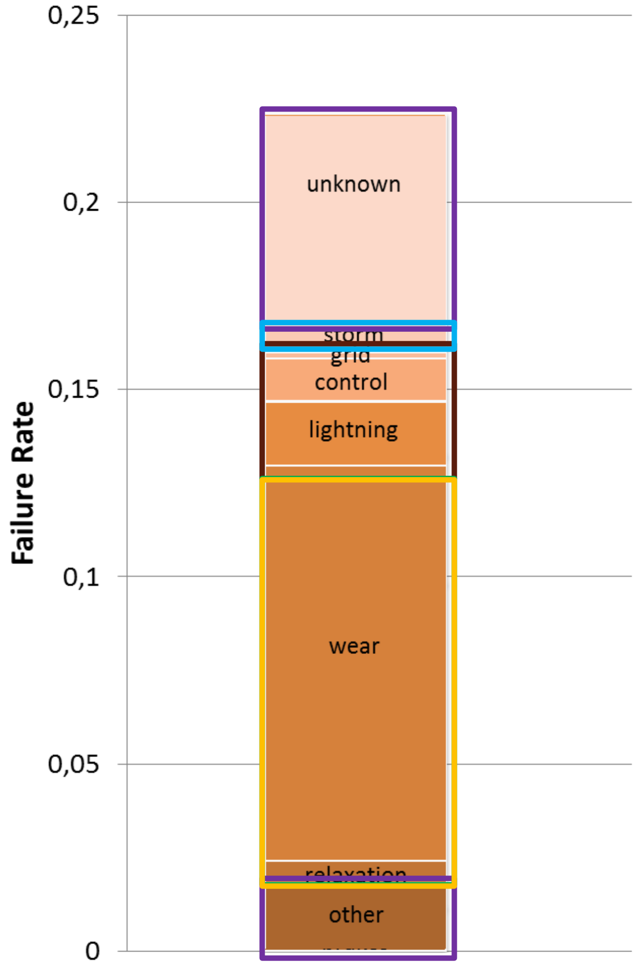
Failure categories
Other

- Early failures
- Aging failures
- Fatigue failures
- Overload failures
- System-specific failures
- Random failures

Parameter estimation
Failure statistics



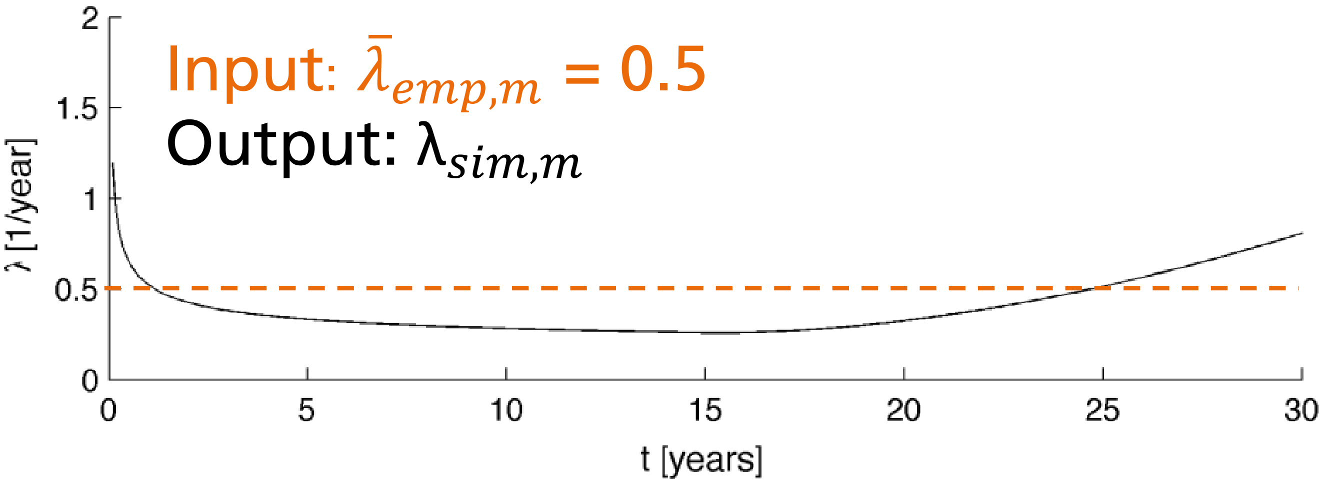
Parameter estimation
Approach



1. Determine the total number of failures for the simulation period
2. Weighting of failure categories

i	Failure category	Share of total failures (%)
1	Random	15%
2	Early	5%
3	Aging	15%
4	Fatigue	55%
5	Overload	10%

Parameter estimation
Approach

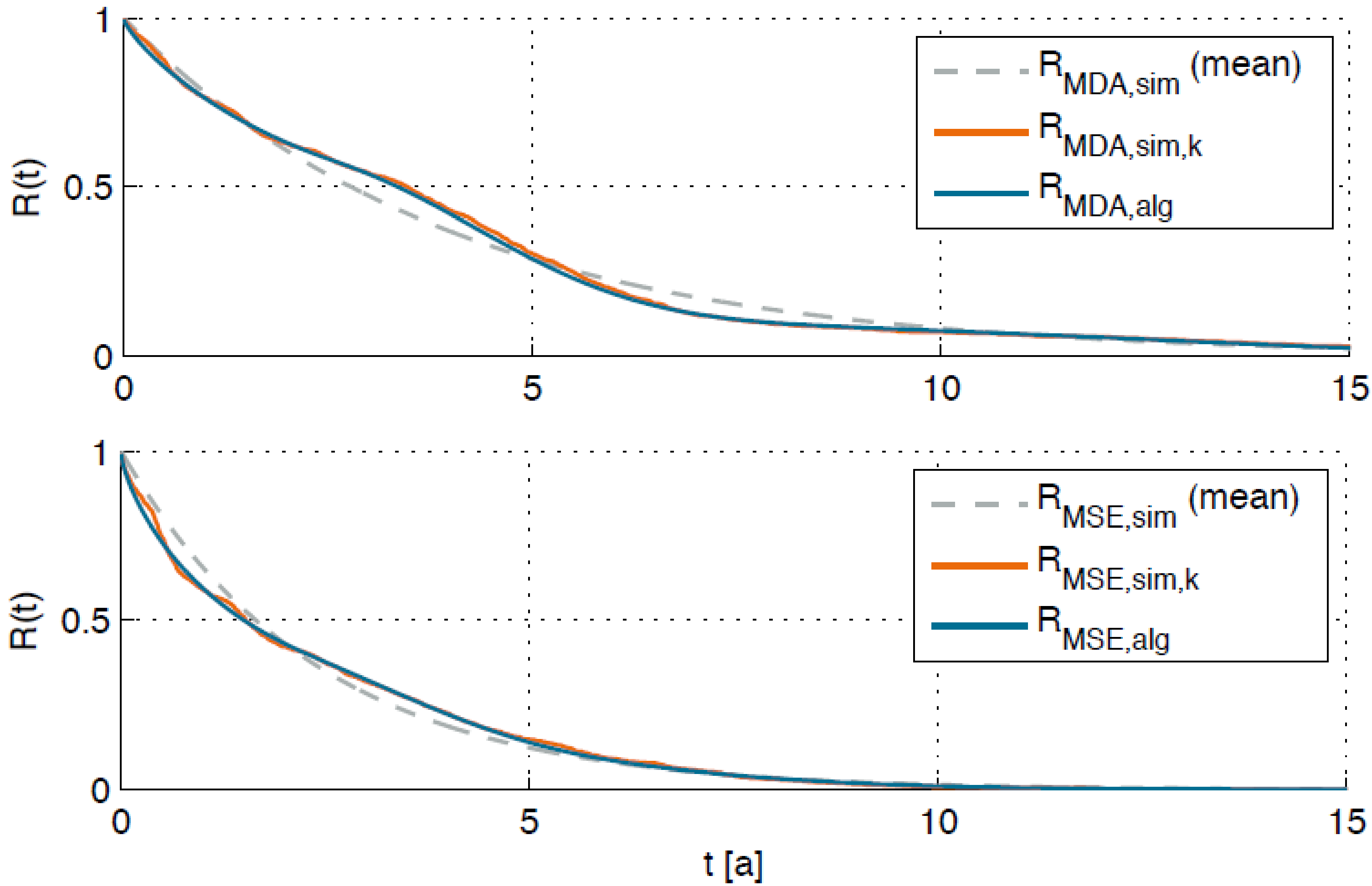


1. Determine the total number of failures for the simulation period
2. Weighting of failure categories
3. Initialize parameters
4. Calculate deviation
5. Optimize Simulation parameter

$$e_{sim,m} = \bar{\lambda}_{emp,m} - \bar{\lambda}_m$$

$$e_{sim,m} \approx 0$$

Simulation results
Component reliability



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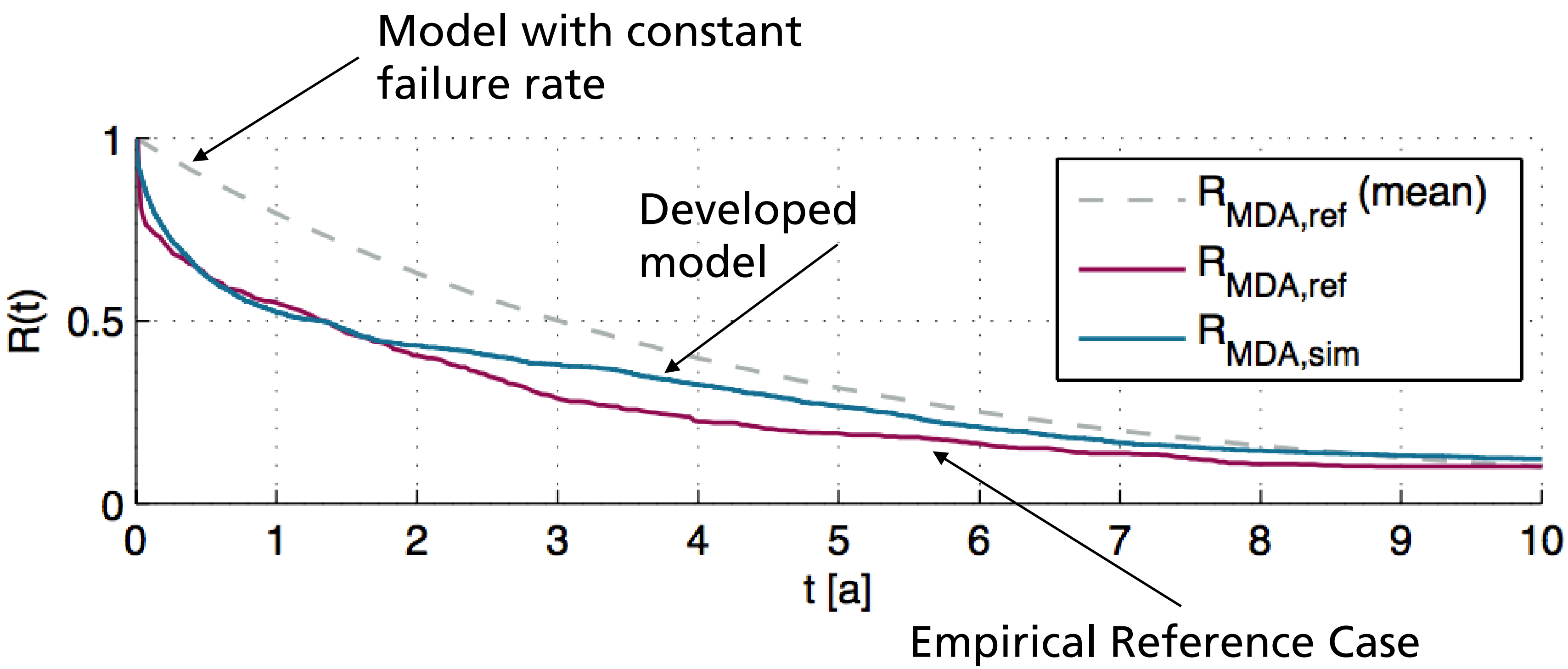
Simulation results
Validation



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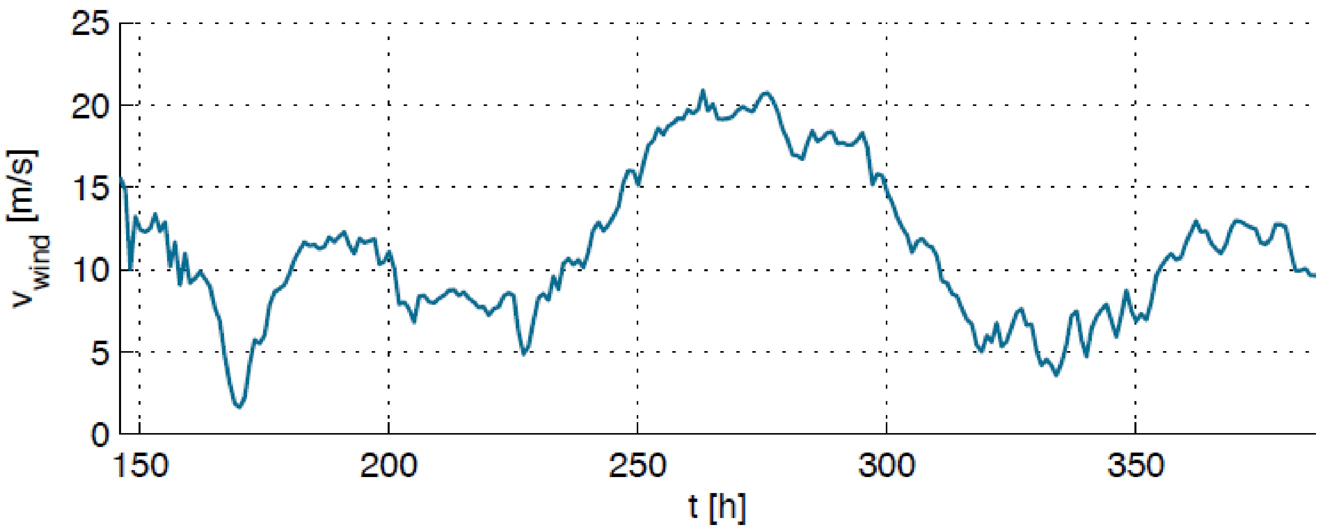
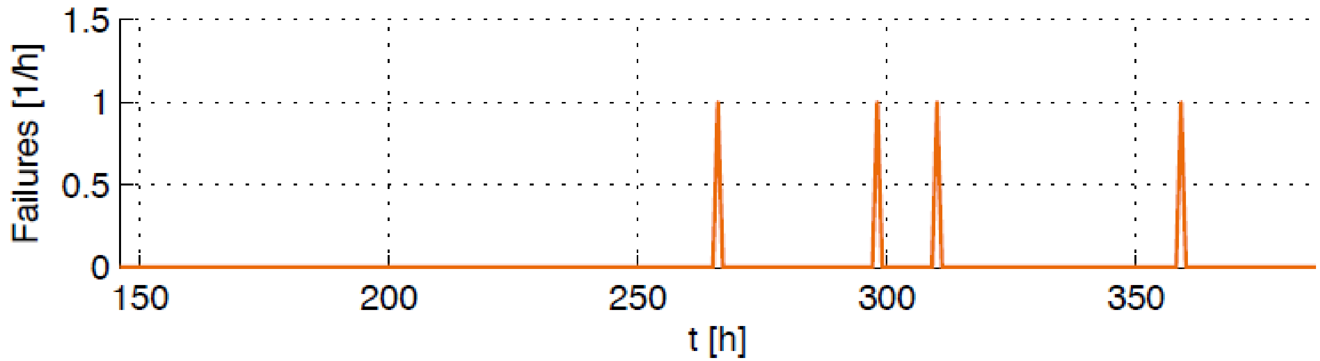
Simulation results
Overload failures





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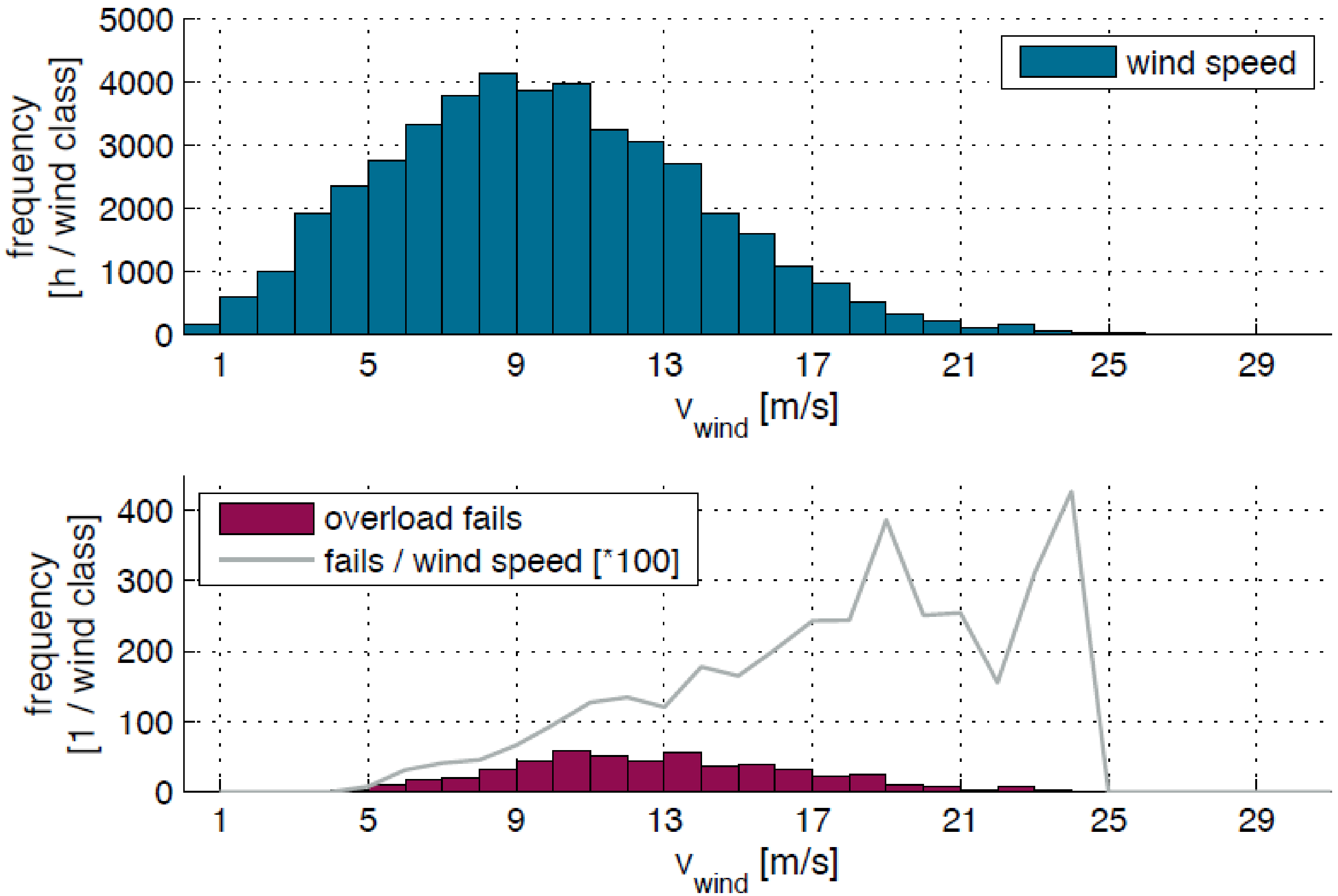
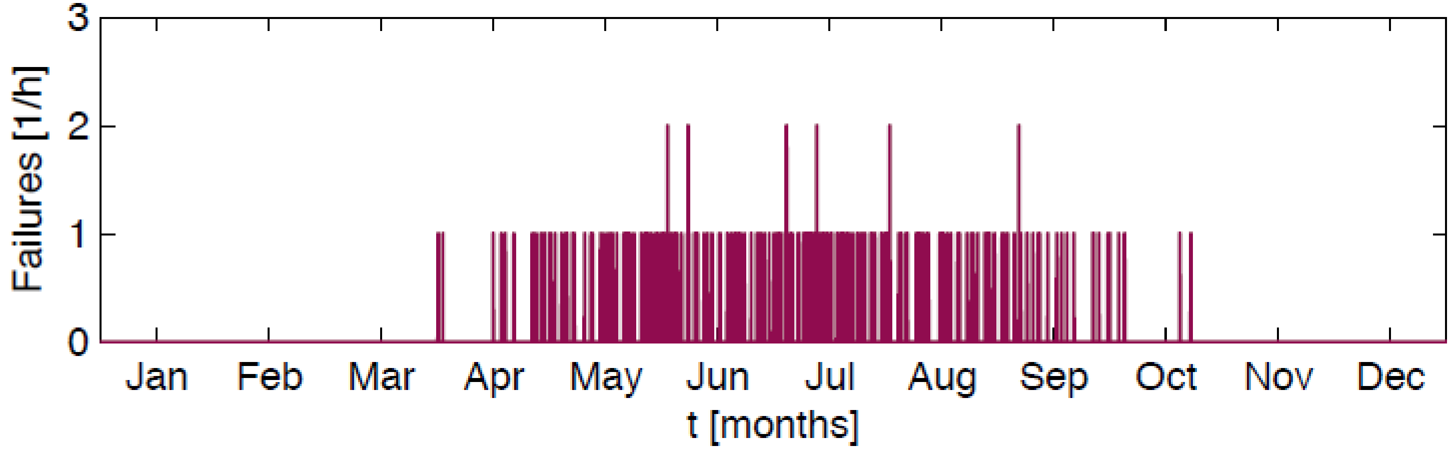
Simulation results
Overload failures



Simulation results
Lightning strikes



Conclusion

- Modelling the failure behaviour of wind turbines is an essential part of offshore simulation software
- failure model based on a reliability-block-diagram has been proposed
- incorporates different failure categories
- essential for better including preventive maintenance strategies
- include increased failure rates at higher wind speed and seasonal effects on failures due to lightning or icing
- Failure statistics using a systematic approach of gathering reliability information are indispensable

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Reliability and maintenance strategies
Wind farm planning and operation

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