COST Action
TU 1402

Quantifying the Value of Structural Health Monitoring

Value of SHM Information for the operation of wind parks

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Introduction

A service life extension of wind parks allows for more power production and a significant higher return over investment.

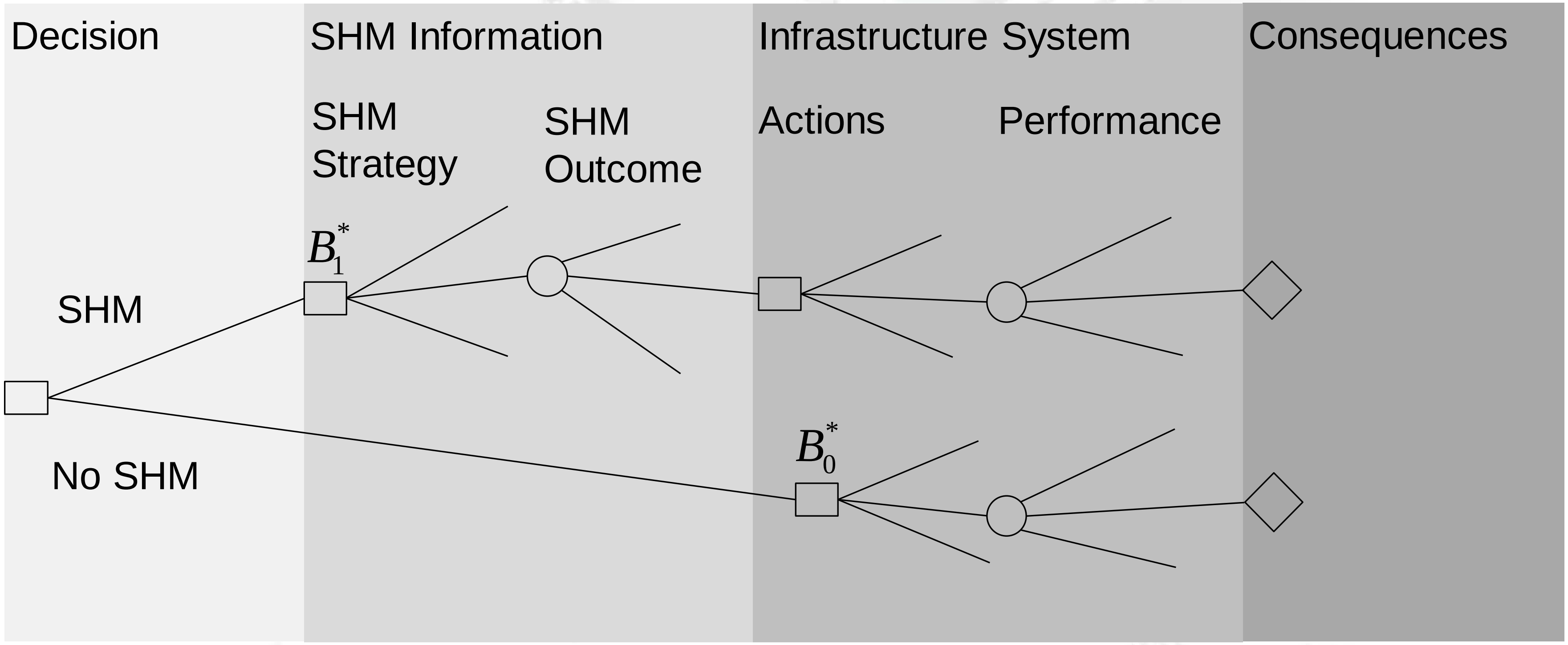
- How does Structural Health Monitoring (SHM) Information contribute to a service life extension of wind parks?

- What SHM characteristics are important to facilitate a high Value of Information?

1. Decision scenario

- Decision maker: Wind park operator
- Decision point in time: Wind park commissioning phase
- Objective: Maximization of expected benefits
- Decision variables: 3 SHM strategies
- Life cycle phase: Operation
- Performance: Structural reliability on component, wind turbine and system level with respect to extreme events and fatigue

2. Models and methods



B_1^*, B_0^* Maximis
with/with

Decision Chances Consequences

The Value of Information is defined as the difference between the maximum expected utility considering SHM information $\boldsymbol{i}$ (u_i^*), and the maximum expected utility without SHM information (u_0^*).

$$VoI = B_1^* - B_0^*$$

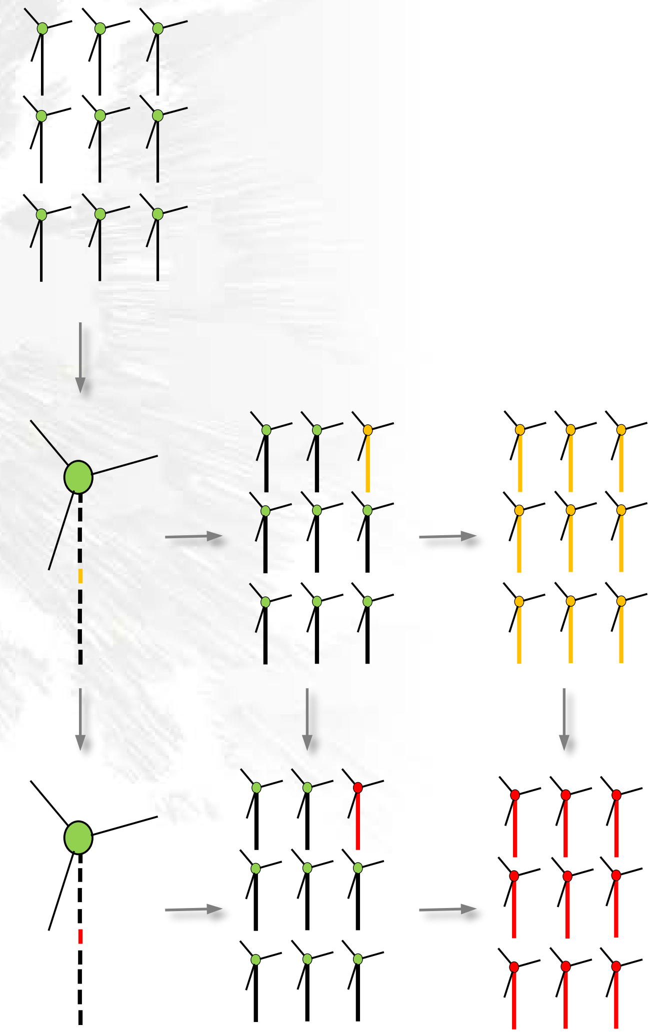
$$B_0^* = \max_{\mathbf{a}} E'_{\mathbf{\Theta}}\left[u\left(\mathbf{a},\mathbf{\Theta}\right)\right]$$

$$B_1^* = \max_{\mathbf{i}} E_{\mathbf{Z}|\mathbf{i}}\left[\max_{\mathbf{a}} E''_{\mathbf{\Theta}|\mathbf{Z}}\left[u\left(\mathbf{i},\mathbf{Z},\mathbf{a},\mathbf{\Theta}\right)\right]\right]$$

The utilities depend on the SHM outcomes $\mathbf{Z}$, the actions $\mathbf{a}$ and the system states $\mathbf{\Theta}$.

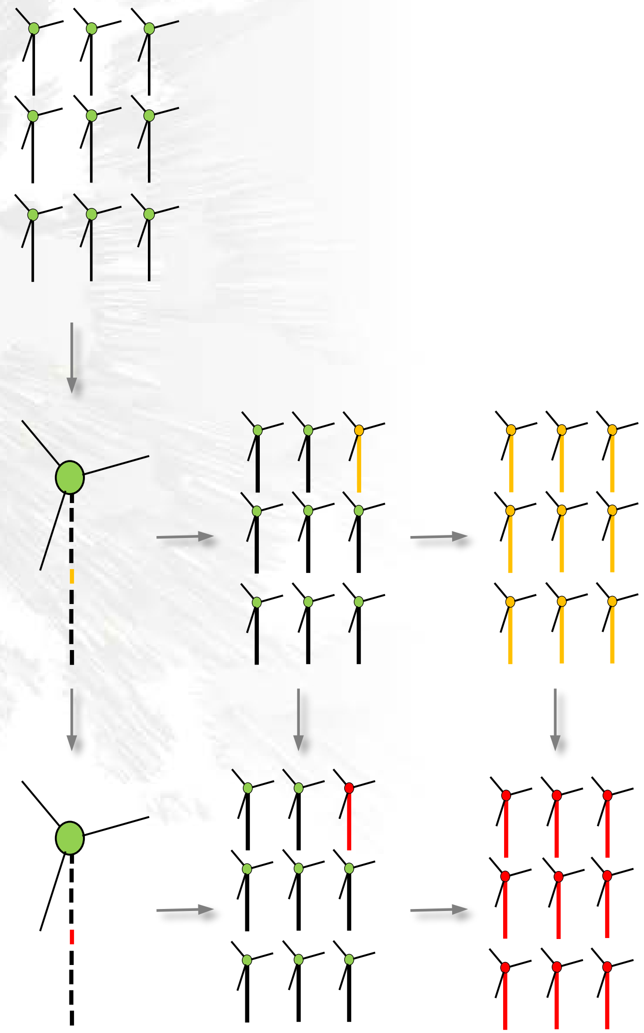
2. Models and methods

System state	Description and system model
Intact	System operation
Constituent damage and failure	Component fatigue damage
	Component failure in dependency of damage states
	Wind turbine fatigue damage (series of components)
	Wind turbine failure in dependency of damage states (series of components)
System damage and failure	Wind park fatigue damage (Brittle Daniels system)
	Wind park failure in dependency of wind park damage state (Brittle Daniels system)

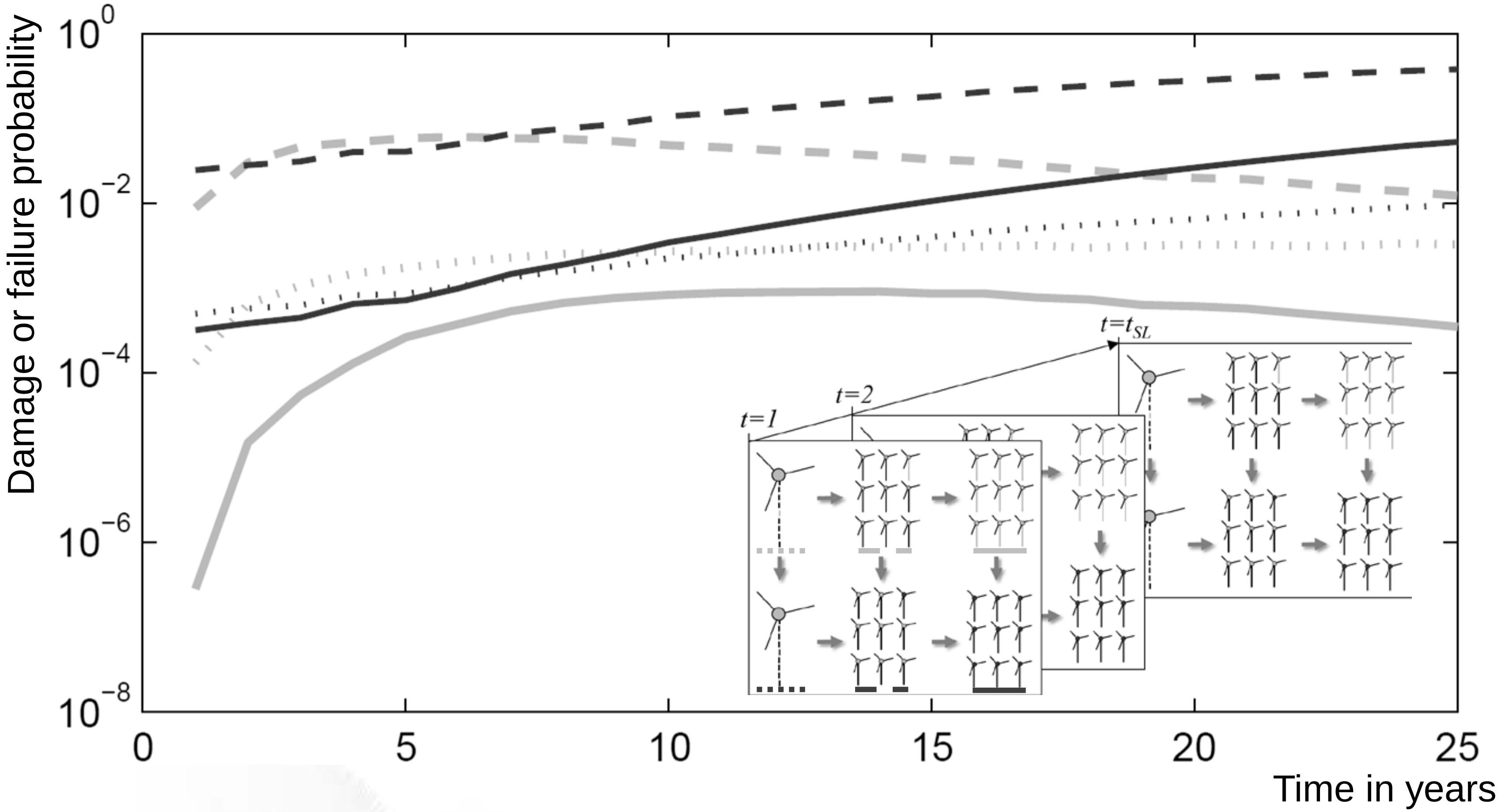


2. Models and methods

System state	Benefits, costs and consequences
Intact	Power production and operation costs
Constituent damage and failure	1.0 % of component investment at time of damage
	Component investment and corresponding part of SHM system investment at time of failure
	1.0 % of wind turbine investment at time of damage
	Wind turbine and corresponding part of SHM system investment at time of failure
System damage and failure	1.0 % of wind park investment at time of damage
	Wind park and SHM system investment at time of failure and loss of power production for the time of failure to service life end



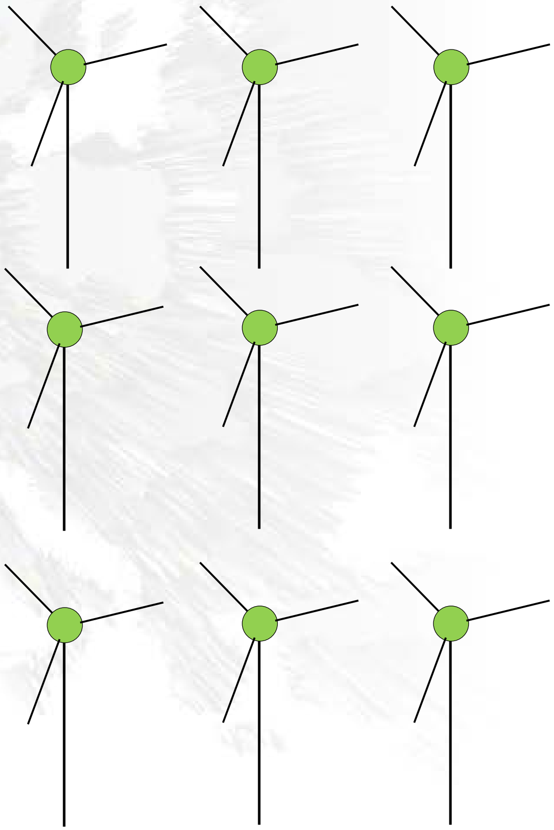
2. Models and methods: System, constituent and component hazard, damage and failure modelling



2. Models and methods: System functionality

A generic wind park with 10 wind turbines is assumed for which Capital, Operational and Abandonment Expenditures (CAPEX, OPEX and ABEX) are calculated.

- Feed-in-tariff: 0.12 Euro
- Nominal capacity: 5.00 MW
- Turbine investment: 20.0 Million Euro
- Turbine availability factor: 0.95
- Wind park operation: 0.02 1/a
- Nominal capacity availability factor: 0.45
- Discount rate: 0.05



OPEX includes operation and maintenance costs of the wind turbines (about 50%) and a small part for the structural integrity management.

2. Models and methods: Pre-posterior modelling of SHM Information

SHM information are characterised by type, its precision and costs.

- Realization of the model uncertainty are known due to SHM performed on a built structure. All possible realizations are accounted for.
- The SHM precision is accounted for also including statistical uncertainties.
- SHM system investment, installation, operation and replacement every 10 years are considered.

2. Models and methods: Pre-posterior modelling of SHM Information

SHM Strategy 1: Fatigue loading

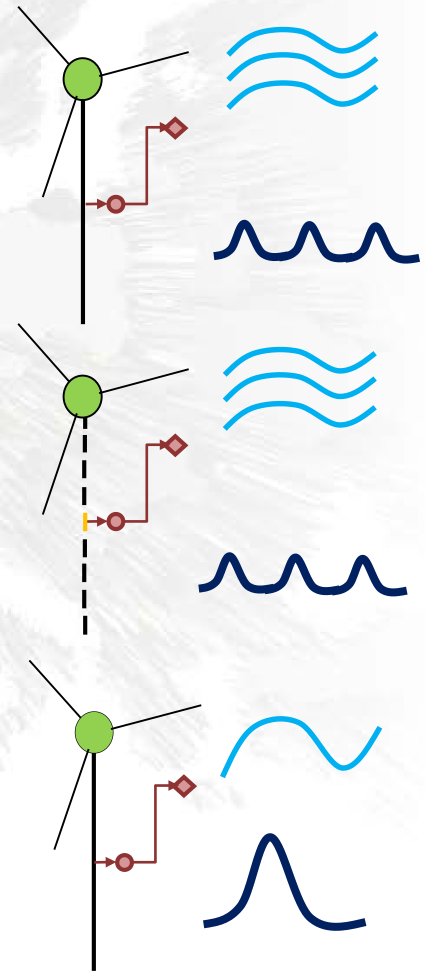
- Pre-posterior model of component fatigue loading measurement

SHM Strategy 2: Hot spot monitoring

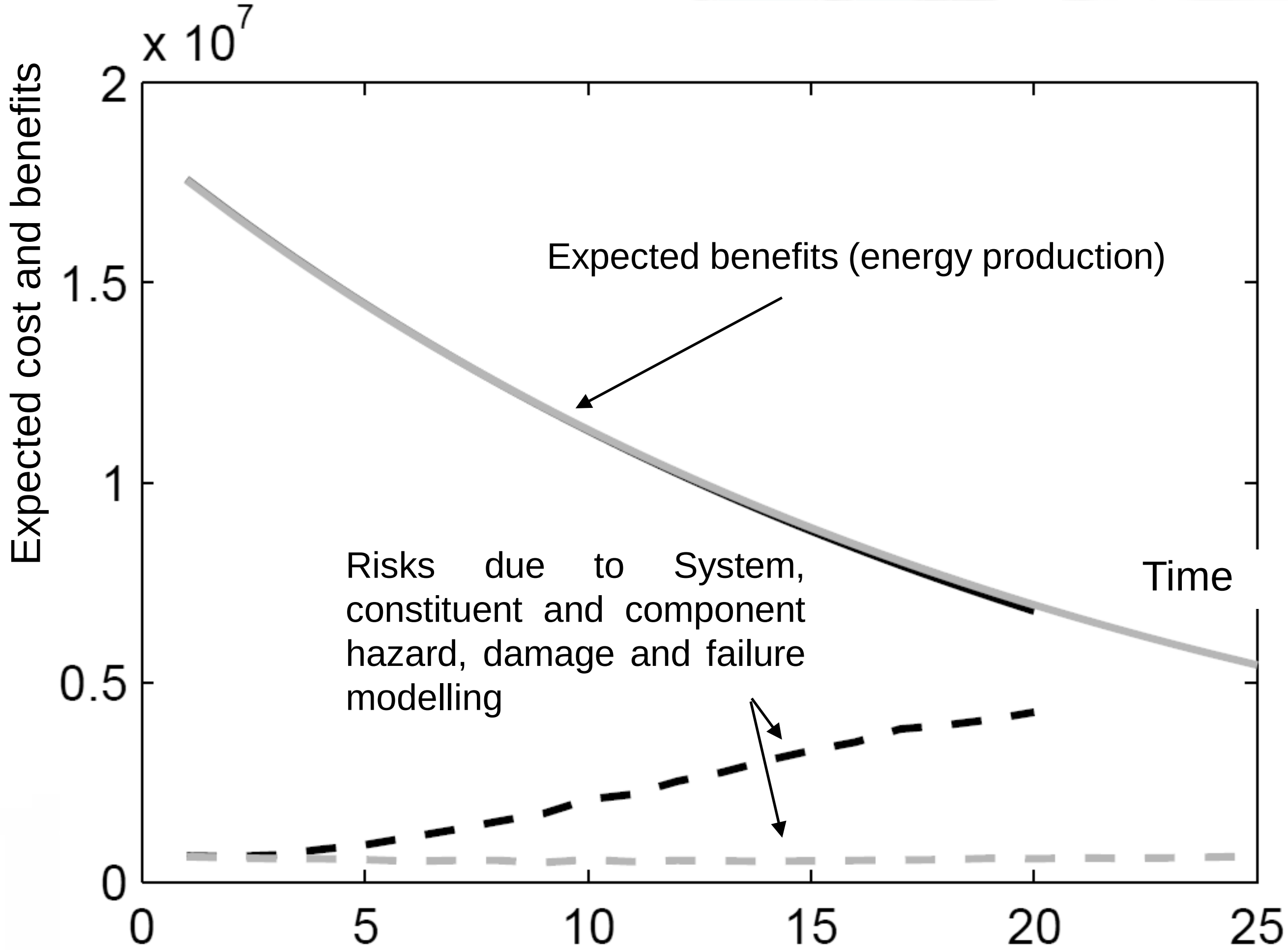
- Pre-posterior model of hot spot stress range measurement

SHM Strategy 3: Extreme load monitoring

- Pre-posterior model of extreme loading measurement

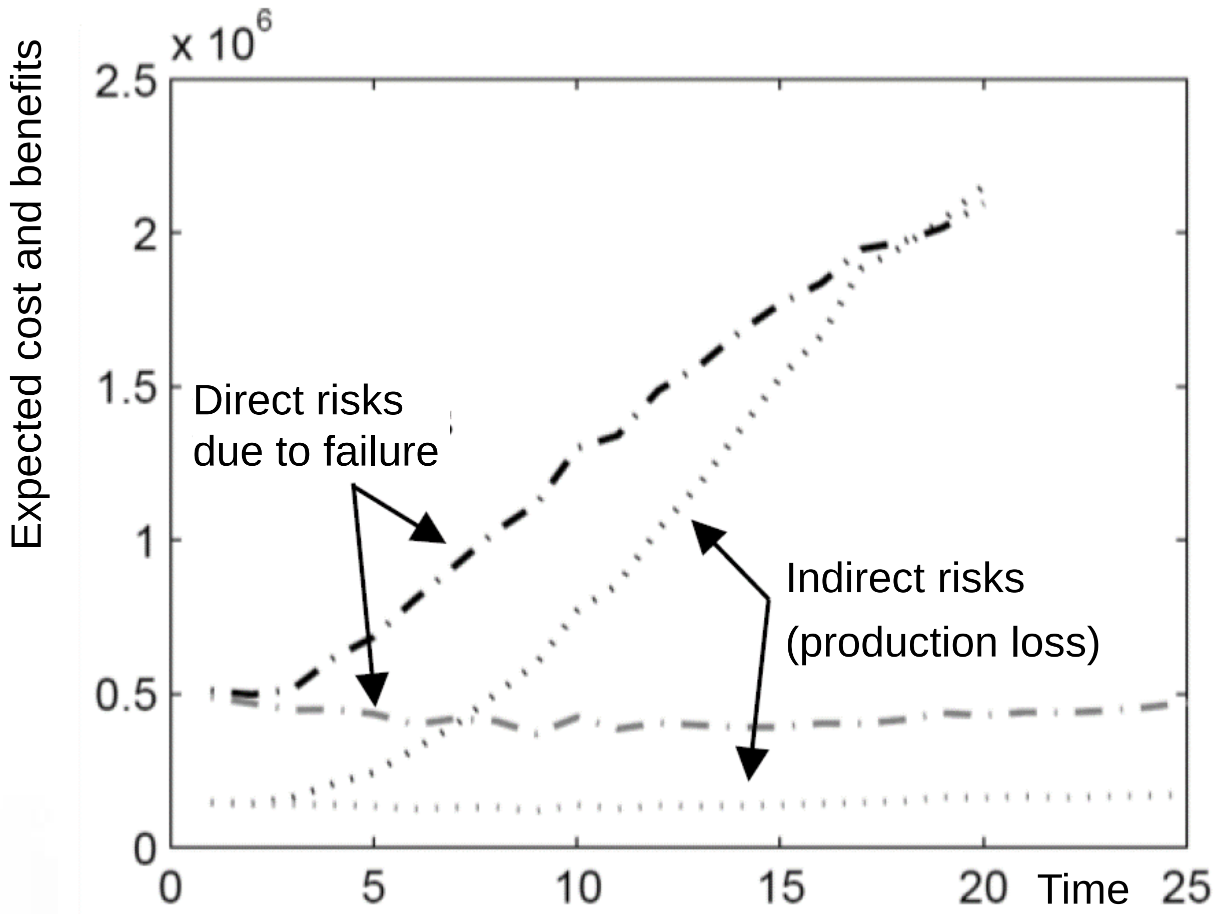


3. Results



x 10^7
Expected cost and benefits
2
1.5
1
0.5
0
0
5
10
15
20
25
Expected benefits (energy production)
Risks due to System, constituent and component hazard, damage and failure modelling
Time

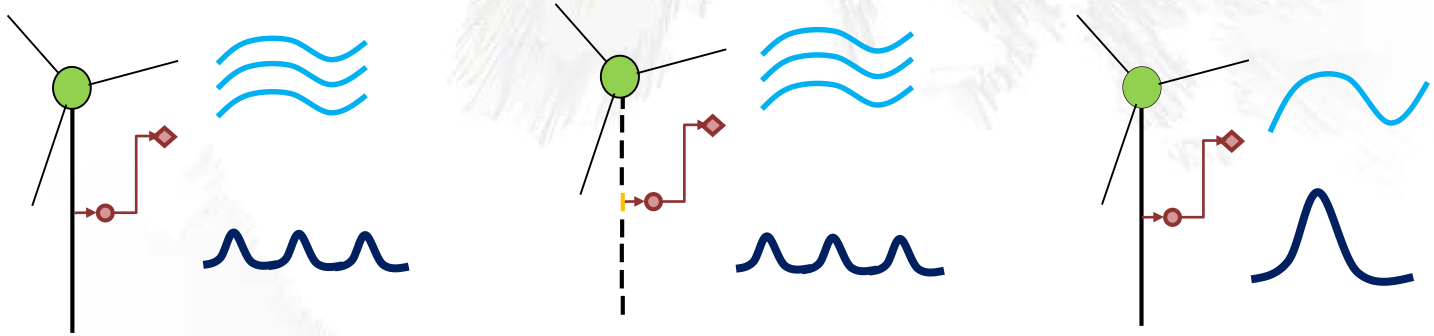
3. Results



x 10^6
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
Time
Expected cost and benefits
Direct risks
due to failure
Indirect risks
(production loss)

4. Value of SHM Information

No.	Strategy	Value of Information	
		VoI_i	$\overline{VoI_i}$
1	Component loading monitoring	$4.9 \cdot 10^{7}$	$2.7 \cdot 10^{-1}$
2	Hot spot monitoring	$6.1 \cdot 10^{7}$	$3.3 \cdot 10^{-1}$
3	Wind turbine loading monitoring	$-1.6 \cdot 10^{6}$	$-8.8 \cdot 10^{-3}$



4. Value of SHM Information

- SHM Strategy 1: Fatigue loading leads to 27% expected benefit increase in relation to no SHM utilisation.

- SHM Strategy 3: Extreme load monitoring leads to a decrease of expected benefits.

No.	Strategy	Value of Information	
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Conclusions

- Wind park service life extension is not optimal without SHM as the risks of structural damage and failure are too high.
- Wind park service life extension is only optimal with additional SHM information of high precision.
- SHM should contain information about the fatigue damage mechanism

Thöns, S., M. H. Faber and D. Val (2017). On the Value of Structural Health Monitoring Information for the Operation of Wind Parks. ICOSSAR 2017, Vienna, Austria

Thank you for your attention

http://www.cost-tu1402.eu/