Using probability bounding to improve decision making for offshore wind planning in industry

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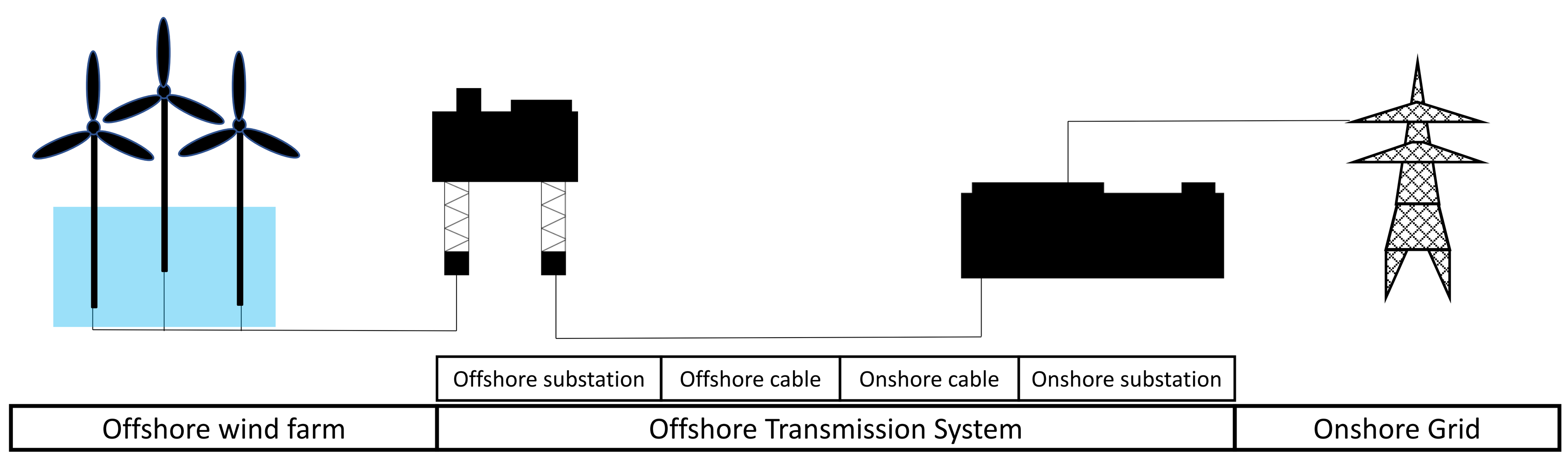


Offshore wind asset and operations planning

decisions

- amount & type of components (platforms, cables, transf's, . . .)
- location/layout of components
- export AC or DC
- level of redundancy
- batteries, hydrogen, . . .

uncertainties

- component reliability
- wind $\rightarrow$ energy produced
- environmental conditions $\rightarrow$ maintenance
- *critical: subsea export cable*

How to solve this planning problem?

- cross discipline academic expertise
  engineering $\leftrightarrow$ mathematics
- industry understands key economic drivers
- importance of communication
  academia $\leftrightarrow$ industry
  industry $\leftrightarrow$ end users
- end user considerations
  - visualisation
  - simple yet accurate language
  - represent their uncertainty
  - explain uncertainty in outcome

Engineering

- develop new technologies
- engineering system design
- data processing

ORE Catapult

- bridge academia and industry
- insight in key industry problems
- project steering

Mathematics

- mathematical modelling, methodology
- optimization, algorithms
- uncertainty quantification

Kinewell Energy

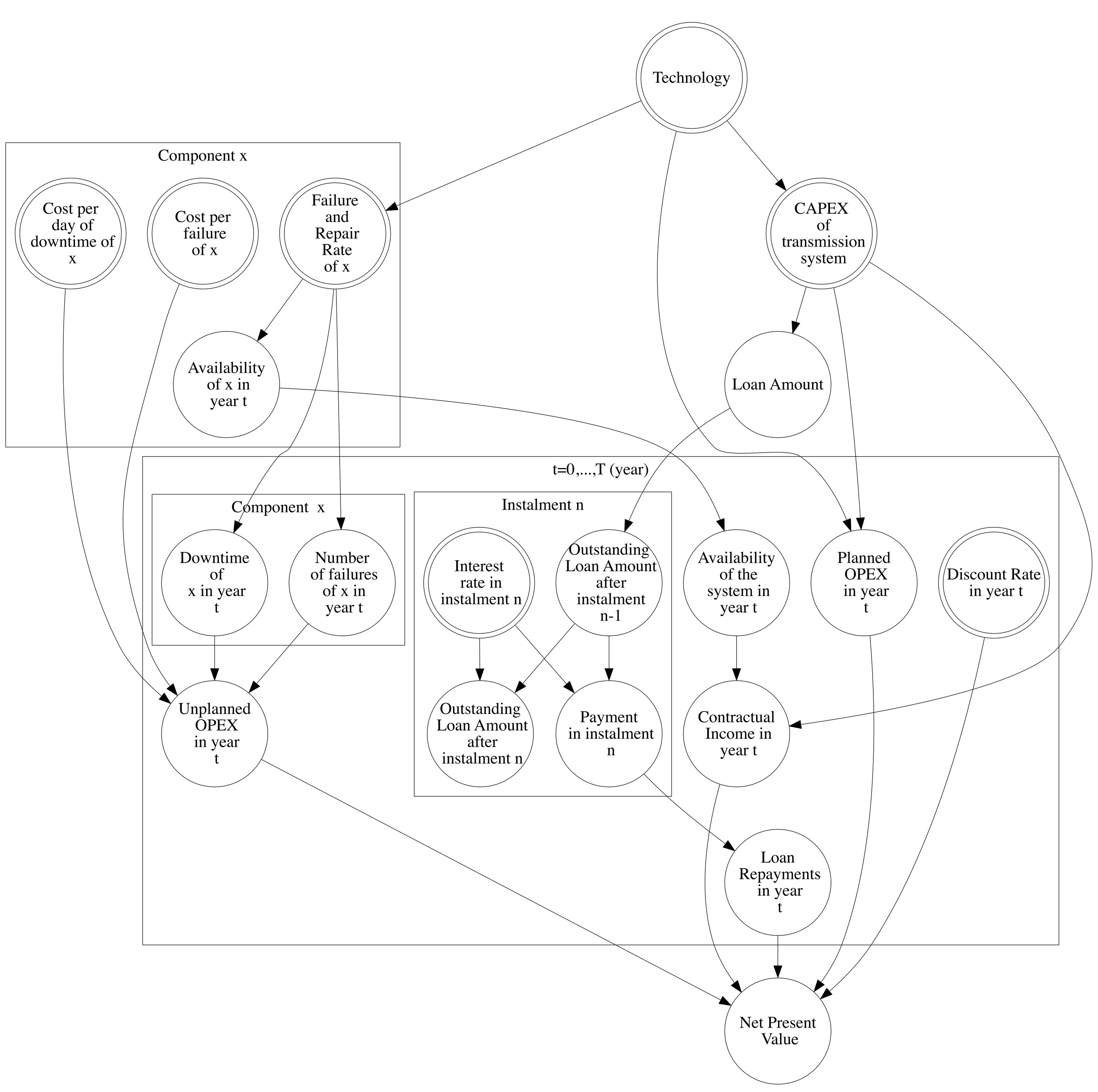
- software and user interface design
- engineering expertise & integration
- commercialisation, sales, investment

Model

- D represents full set of planning designs
- Θ represents set of model parameters
- uncertainty described via expectation given $d \in D$ and $\theta \in \Theta$
- typically aim to maximize net present value (or similar) [2, 3]:

$$\mathrm{NPV}(d,\theta) = \mathbb{E}\left(\sum_{t=0}^{T-1} \frac{\mathrm{INCOME}_t - \mathrm{CAPEX}_t - \mathrm{OPEX}_t}{(1+r)^t} \middle| d,\theta\right) \tag{1}$$

- T is lifetime, r is discount rate



Imprecise probability

- can represent end user severe uncertainty in failure and repair rates of critical components such as subsea cables [3]
- performed by sensitivity analysis on model parameters θ
- use *interval dominance* on NPV (net present value) [1]

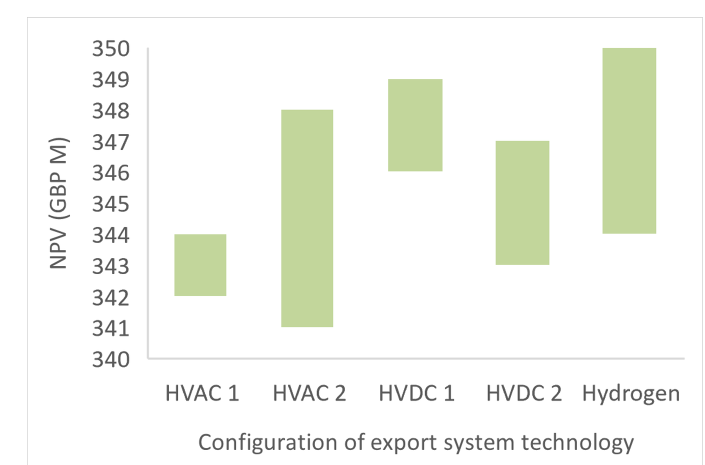
$$\underline{\mathrm{NPV}}(d) = \min_{\theta\in\Theta} \mathrm{NPV}(d,\theta) \qquad \overline{\mathrm{NPV}}(d) = \max_{\theta\in\Theta} \mathrm{NPV}(d,\theta) \tag{2}$$

$$D^* = \left\{ d \colon \overline{\mathrm{NPV}}(d) \geq \max_{d'\in D} \underline{\mathrm{NPV}}(d') \right\} \tag{3}$$

- why interval dominance and not maximality or E-admissibility?
  - fast computation
  - handles act-state dependence [1]
  - can visualize lower and upper expectations
  - intuitive: 'optimal choice depends on risk appetite'
- challenges in user interface design
  - how to elicit ranges for sensitivity analysis?
  - visualization of outcome of analysis of a potentially large numbers of designs

Decision support tool: KDOTS

- developed by Kinewell Energy with support of Durham & ORE Catapult, funded by TIGGOR (NTCA)
- integrated into offshore infrastructure optimisation software (SaaS)
- importance of documentation and clear consistent language



[1] Henna Bains, *Offshore transmission systems planning under severe uncertainty*, Ph.D. thesis, Durham University, 2021.

[2] Henna Bains, Ander Madariaga, Behzad Kazemtabrizi, and Matthias C. M. Troffaes, *The impact of offshore transmission regulatory regimes on technology choices*, CIGRE Symposium, 2019.

[3] Henna Bains, Ander Madariaga, Matthias C. M. Troffaes, and Behzad Kazemtabrizi, *An economic model for offshore transmission asset planning under severe uncertainty*, Renewable Energy **160** (2020), 1174–1184.

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