Knowledge gaps: assessing combinations of probabilities and assumptions of cost and duration of impacts on grid assets

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Addressing the gap: Identification of the duration of the outage

To better understand underlying assumptions on project side, we included several questions concerning the approach and assumptions taken by the participants when it comes to an outage

Questions asked

What is **the estimated rebuild time** in case of damage from the climate hazard(s) [...]?

What assumptions do you make regarding the **probability of outage after hazards, and the duration of rebuilding the asset** in your decision-making?

Answers received

"Depending on the equipment concerned and its availability - 1 day up to weeks"

"From a few days to a few months."

"Depends on the hazard, zone of impact and intensity"

"It depends on the hazards and the asset"

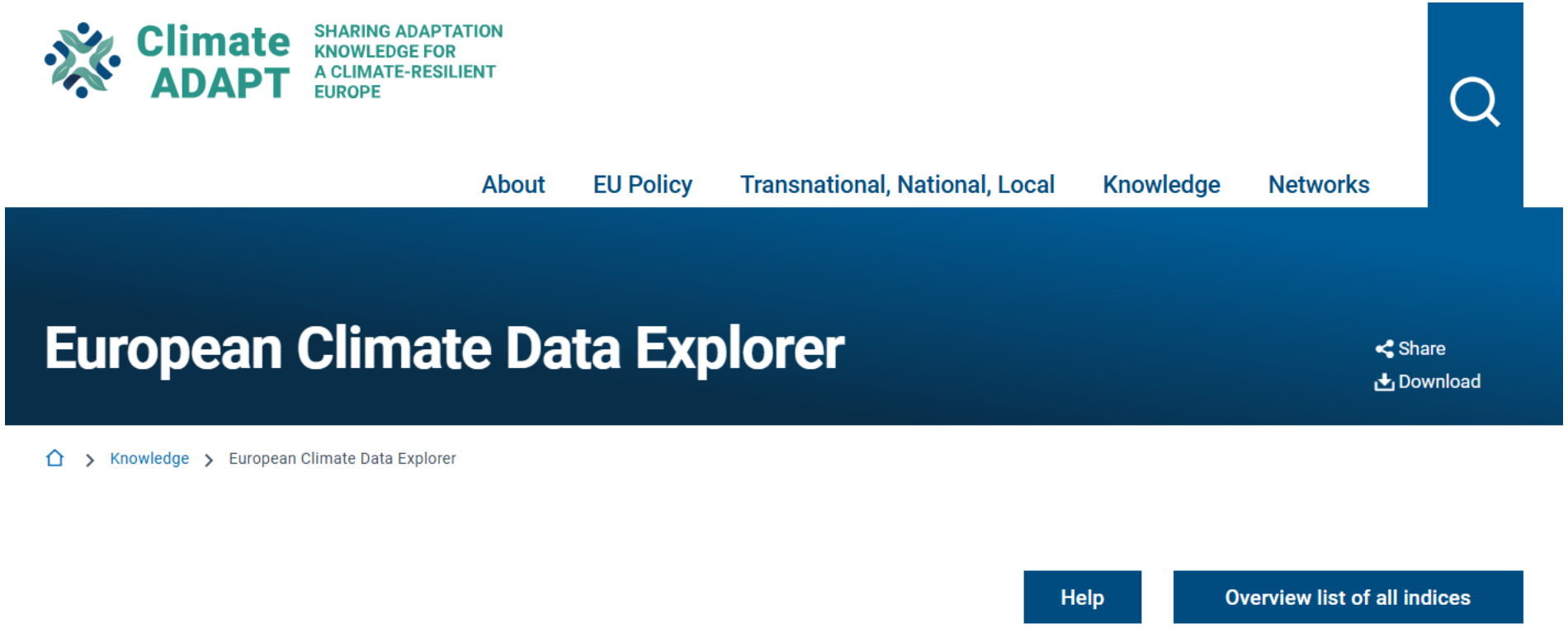
"No blanket assumptions—outage probabilities and rebuild durations are asset- and hazard-specific. [...]"

Conclusion derived

1. You can't define one standard duration for all hazards
2. Intensity in combination with Probability of occurrence is decisive
3. probability changes over time (reoccurrence)
4. The duration not only depends on the hazard characteristics but also on asset specificities

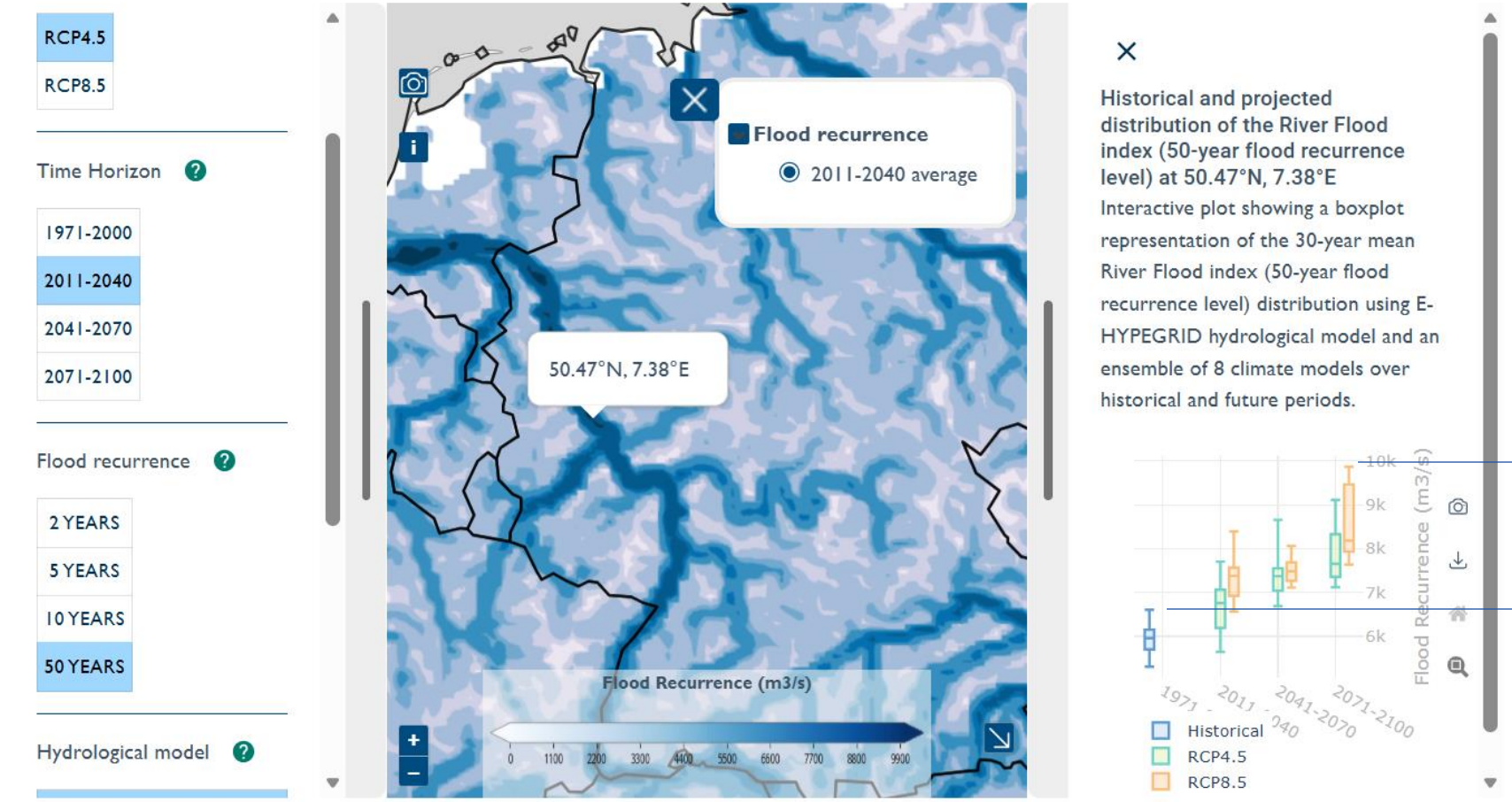
Further thoughts on probability

Could we make use of an existing data base to get spatial information on the probality of occurence?



Example for river floods

Probability of increased intensity increases over time



- Take probability of hazard intensity into account via Monte Carlo simulations → indicator will become a random variable following a distribution

Threshold to plan an asset climate resilient

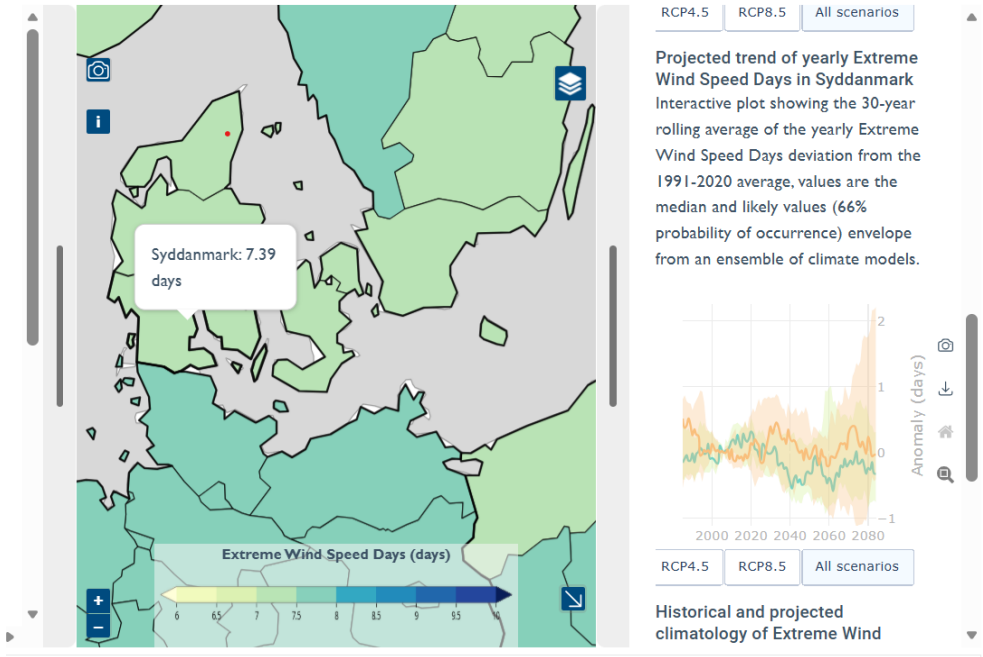
Base line

Content in the European Climate Data Explorer pages is delivered by the Copernicus Climate Change Service (C3S) implemented by ECMWF.

Example wind speed

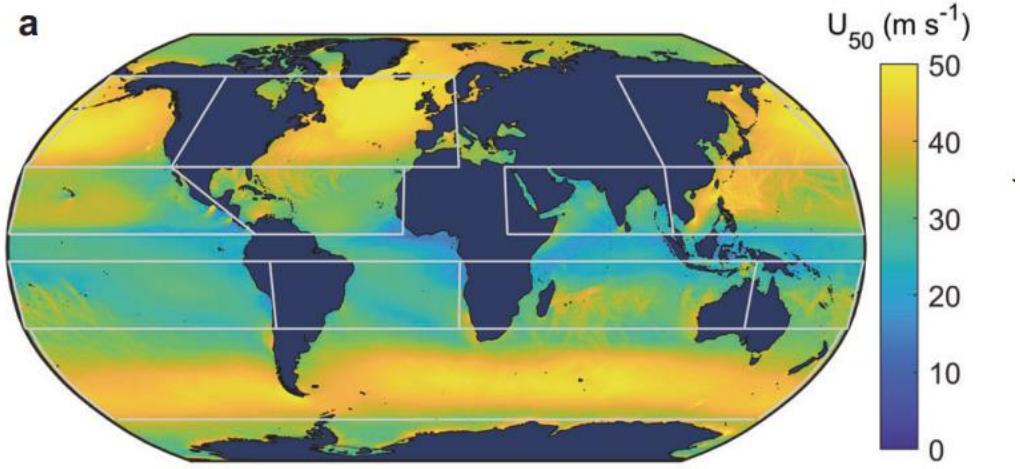
Damage caused by mechanical strain is dependent on the intensity but also on the rate of reoccurence

Reoccurence: Extreme wind days will increase and stress more our infrastructures



[Extreme Wind Days | Indicators | Discover the key services, thematic features and tools of Climate-ADAPT Climate-ADAPT]

Intensity (fifty-year return period wind speed) will also increase here in the case of offshore infrastructures



Zhao, Y., Tao, Y., Chen, Y. *et al.* Increasing extreme winds challenge offshore wind energy resilience. *Nat Commun* **16**, 9529 (2025).

Combining the intensity with probability profiles

The effects of varying probabilities distributions (Equally distributed vs. Rising probability of occurrence over time) while maintaining the assumption of one outage in 25 years.
The intensity can be displayed by introducing Intensity Alternatives A based on scientific literature, with the complexity factor $CF_{Intensity,A} = \frac{Intensity_{Quantile,A}}{Intensity_{Quantile,REF=0.5}}$ normalizing each effect relative to the median.

Overview matrix per Hazard
- Profile of probability
- Intensity alternatives

		Environmental scenarios, i.e. Hazard occurring in year X				
		S1: Outage in Year 1	S2: Outage in Year 2	….	S_X: Outage in Year X	
Alternatives i of intensities for non-adapted Assessment	A1: Intensity Quantile 1	Matrix consisting of all Combination of alternatives of intensity and scenarios for occurrence of the hazard $f_{Hazard} = p_{Occurence,SCenario\ X} * CF_{Intensity,Alternative\ A}$				$NPV_{Alternative\ 1}$
	A2: Intensity Quantile 2					$NPV_{Alternative\ 2}$
	….					$NPV_{Alternative\ 3}$
	A4: Intensity Quantile i					$NPV_{Alternative\ 4}$
Adapted Calculation	No Influence	No need for case sensitive separation over years				$NPV_{adapted}$

For each Alternative: $\Delta NPV = NPV_{Alternative\ A} - NPV_{Adapted}$

With rising probability and increased intensity, should the assessment also include the case that the adapted version is affected?

Assessing the vulnerability of the asset

Reduced capacity

Need to find a way to account for the fact that when a hazard affects a line or component, the extent of damage may change over time.

Stage	Description	Capacity
Initial state (after blackout)	Complete loss of functionality	0 %
Intermediate	Partial recovery phase	0 % < Capacity < 100 %
Full recovery	Normal operation restored	100 %

Time range	Capacity
Hour $t \rightarrow t + d$	0 %
Hour $t + d \rightarrow t + x$	50 %
After $t + x + 1$	100 %

t= blackout time d = duration of outage x = partial recovery period

Open Discussion

In your opinion, should the indicator result in a range of assumptions (e.g. min and max of wind speeds) or should the indicator approach consist of a random variable (e.g. including the quantiles or probability distributions of the hazard intensity) for the occurrence?

In your opinion, how should we account for altering probability of occurrence and intensity of the hazard?

- What is your view on the feasibility of using hazard specific probabilities vs. a cross-hazard approach (using same probabilities for all hazards)?
- What do you think of assessing the rising probability via probability profiles (As shown on the last slide)
- With rising probability and increased intensity, should the **assessment also include the case of the adapted version being affected?**
- What is your view **on the integration of existing hazard risks?** Do you think introducing a complexity factor referenced to the current intensity is sufficient?

How should the duration of the outage of a specific asset be treated?

- Should we use a range of durations?
- What is your opinion **on asset-type specific duration assumptions?**
- What is your opinion **on the assessment of partial outage?**