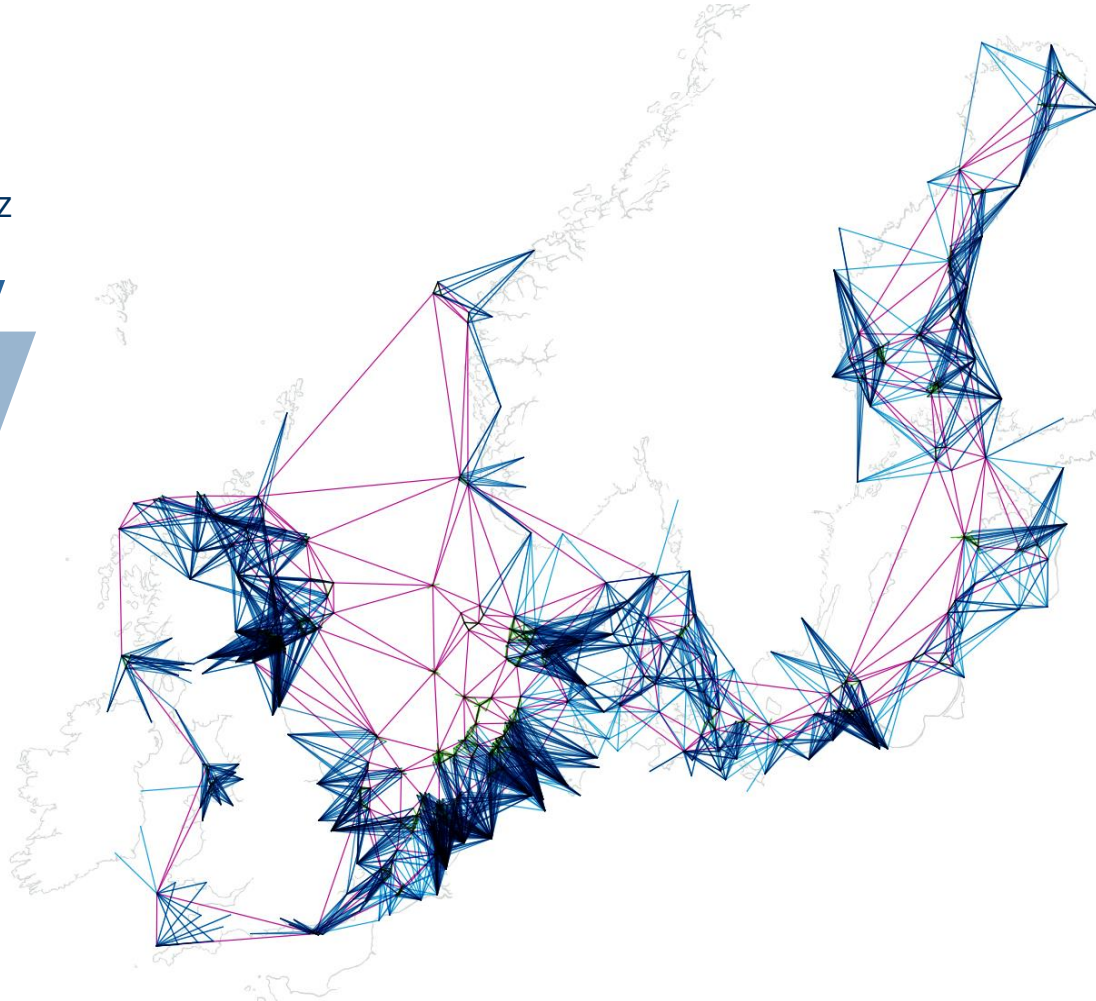
Felix Jakob Fliegner
Chair of Energy Economics, TU Dresden & System of the Future, 50Hertz

Spaghettigrids - Offshore grid development with GIS

First insights for Baltic and North Sea



17th ENERDAY, Dresden // 05.05.2023

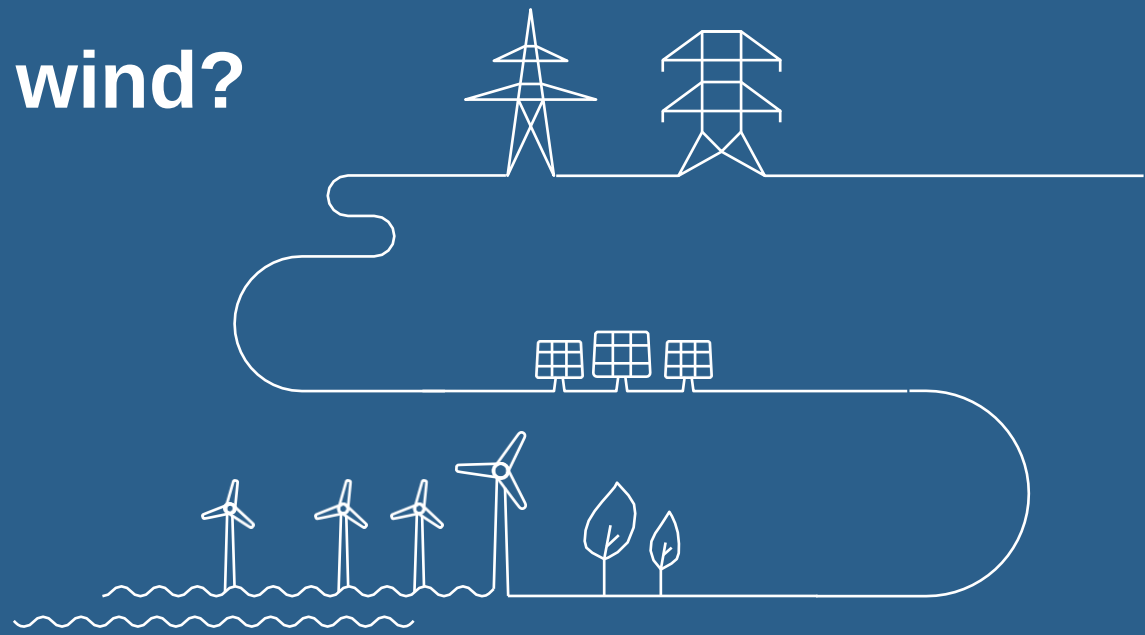
Content of this presentation is subject to the manuscript “High-resolution scenario building support for offshore grid development studies in a geographical information system” submitted to *Energy Strategy Reviews.*
It depicts the sole view of the author and does not allow any conclusion on the positioning of 50Hertz

Content

1. The core challenge – How to connect future offshore wind?
2. Setting up a search graph in GIS – Pencil or GIS?
3. The case of Baltic and North Sea
4. Looking ahead – Coupling with an energy system model

How to connect future offshore wind?

Problem statement and research focus



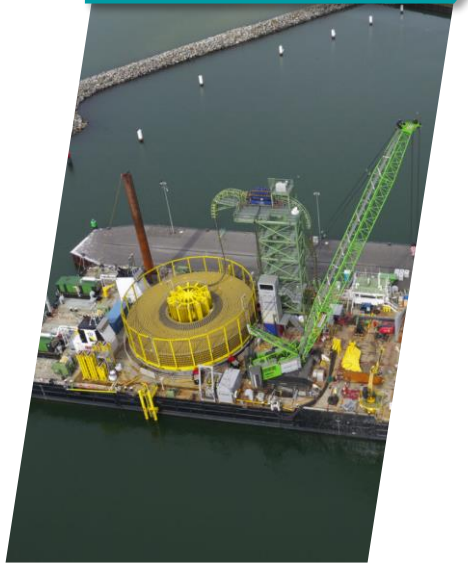
Coiled and laid…

How to bring Offshore Wind ashore

Offshore Wind Farm

Collection / HUB

Sea cable

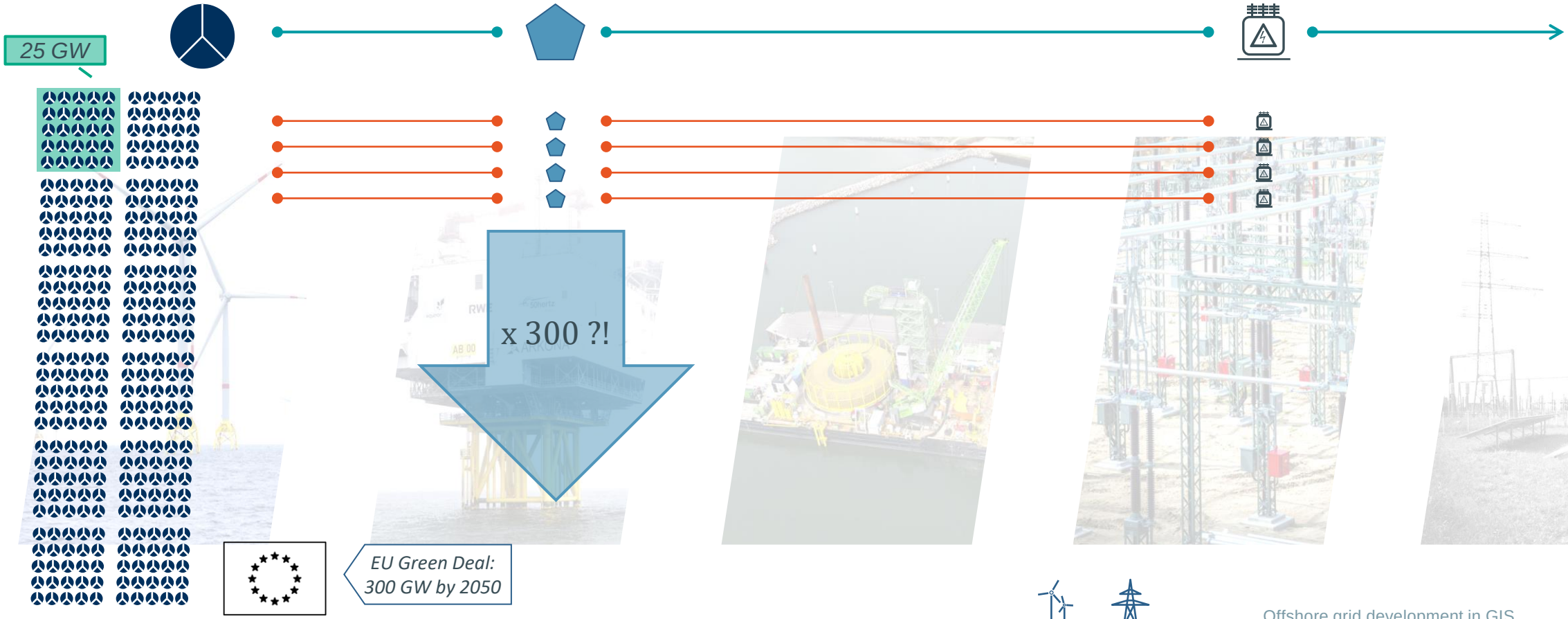


Point of Connection

Pictures: 50Hertz

Spaghetti or Plait?

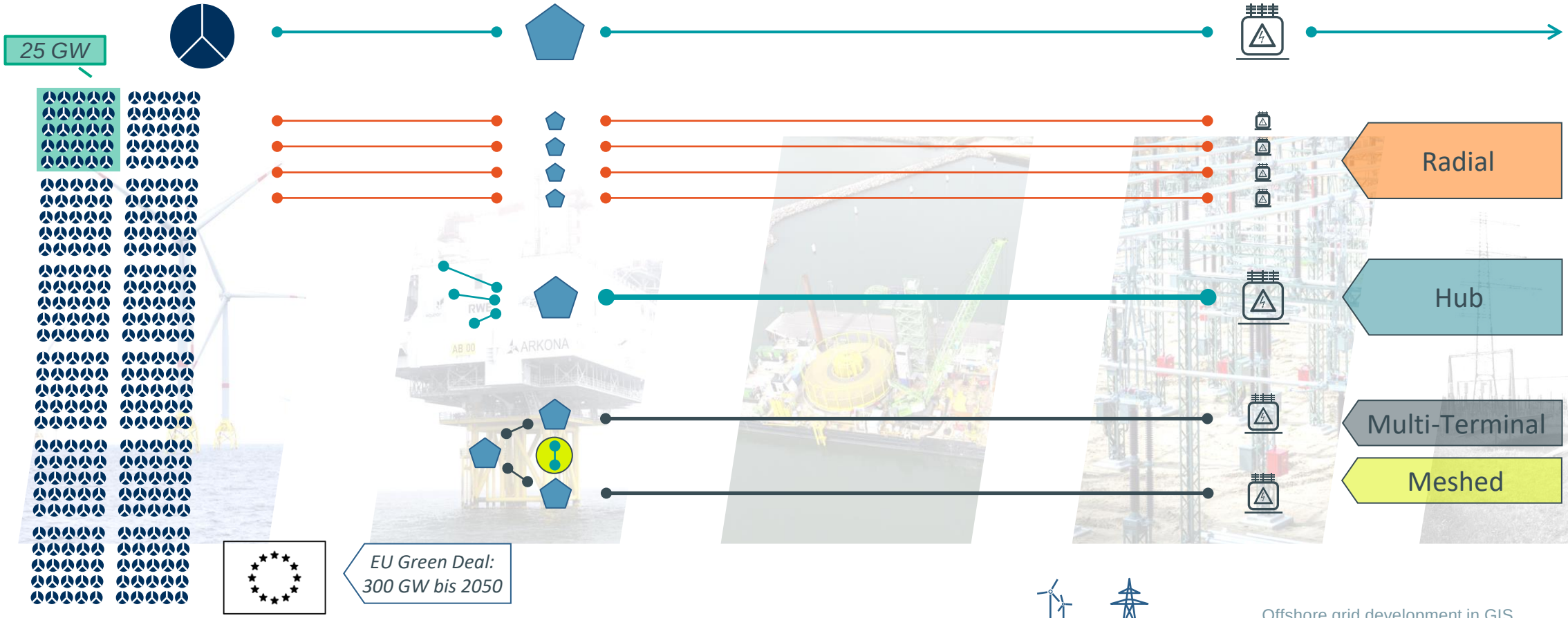
How to connect bulk offshore capacities



Pictures: 50Hertz | EU Icon: the noun project

Spaghetti or Plait?

How to connect bulk offshore capacities

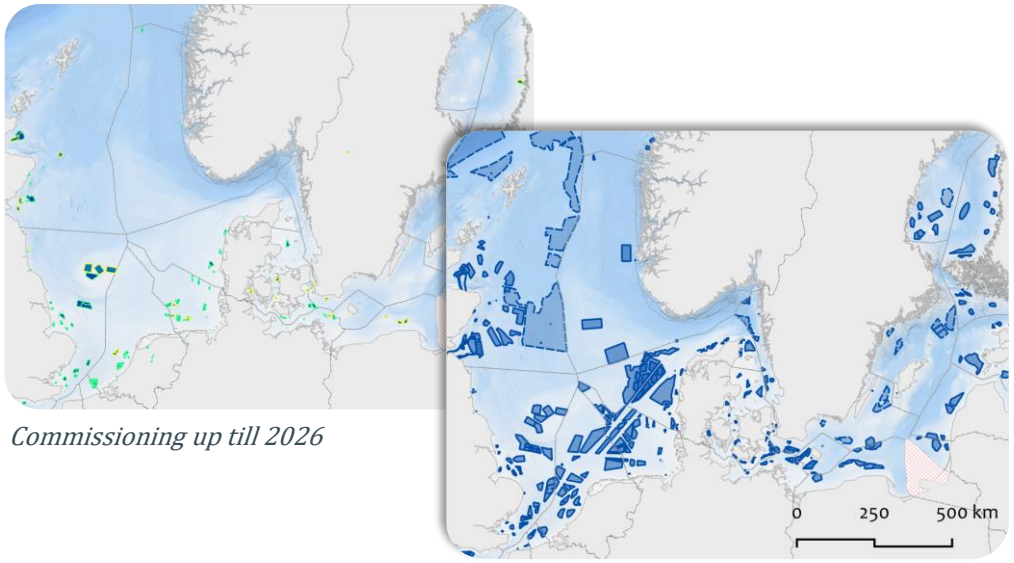


Pictures: 50Hertz | EU Icon: the noun project

The EU Green Deal is blue

How to integrate unprecedented amounts of offshore wind efficiently into the energy system?

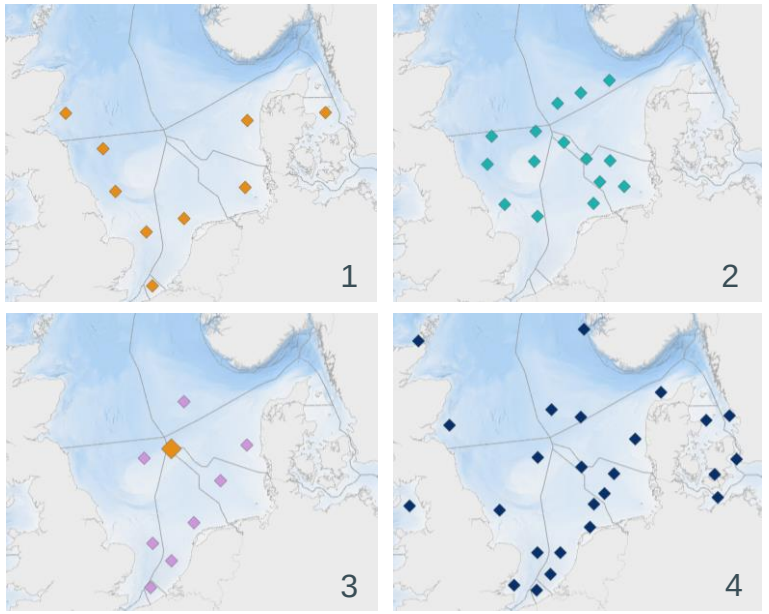
Wind farm development areas in Europe



Commissioning up till 2026

Designation areas

Offshore wind allocation in selected studies

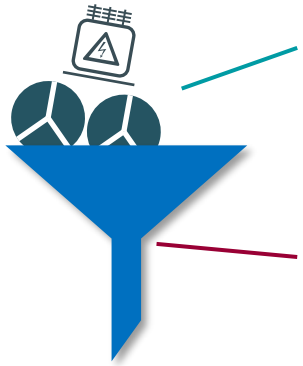


There is a rationale for a high-resolution search graph setup to leverage domain knowledge that would not be accessible in energy system modelling otherwise

Sources: (1) Dedecca et al. 2018, (2) Gea-Bermúdez 2020, (3) Kristiansen et al. 2018, (4) Konstantelos et al. 2017

Work smart, nor hard

Research focus is the identification of investment candidates



*How **could** wind farms, hubs and countries be interconnected in the future?*

*How to identify **relevant** investment candidates?*

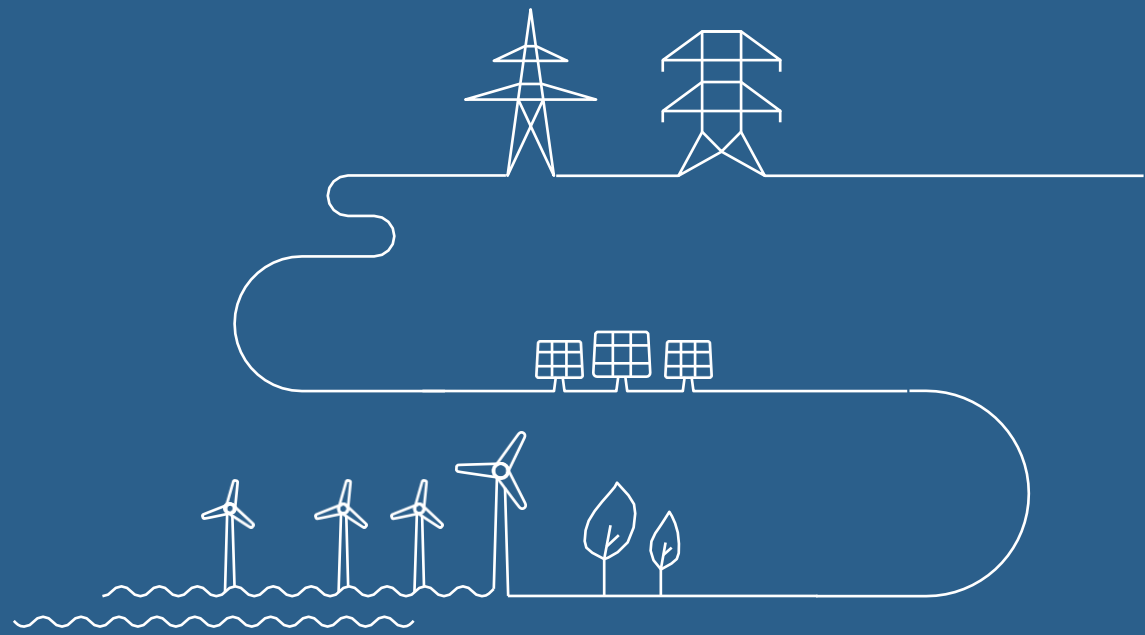
Scenario data → **Investment candidates** → Optimisation of investment decisions → Power flow calculations → Final Results

Keep this "small" for computational tractability

This presentation proposes a workflow in a Geographical Information System (GIS) to identify investment candidates automatically and at large scale

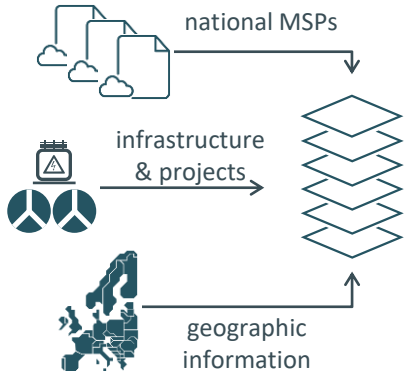
Pencil or computer?

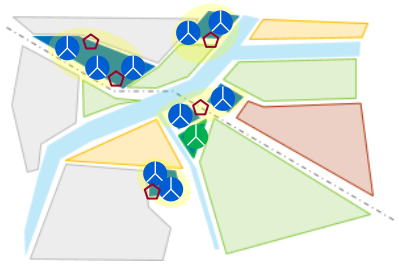
Setup of a search graph in GIS

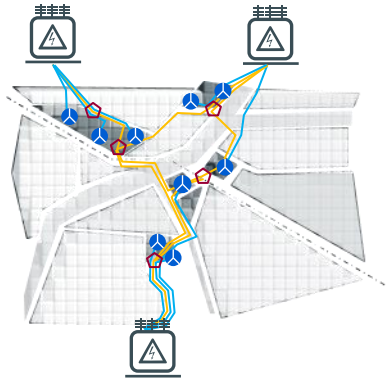


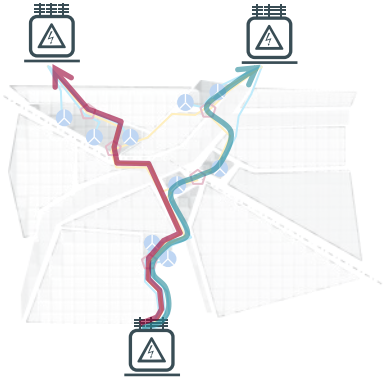
Search graph – setup of candidate lines for investment

Input Data → Optimisation of investment decisions → Power flow calculations → Final Results









I Data consolidation — QGIS

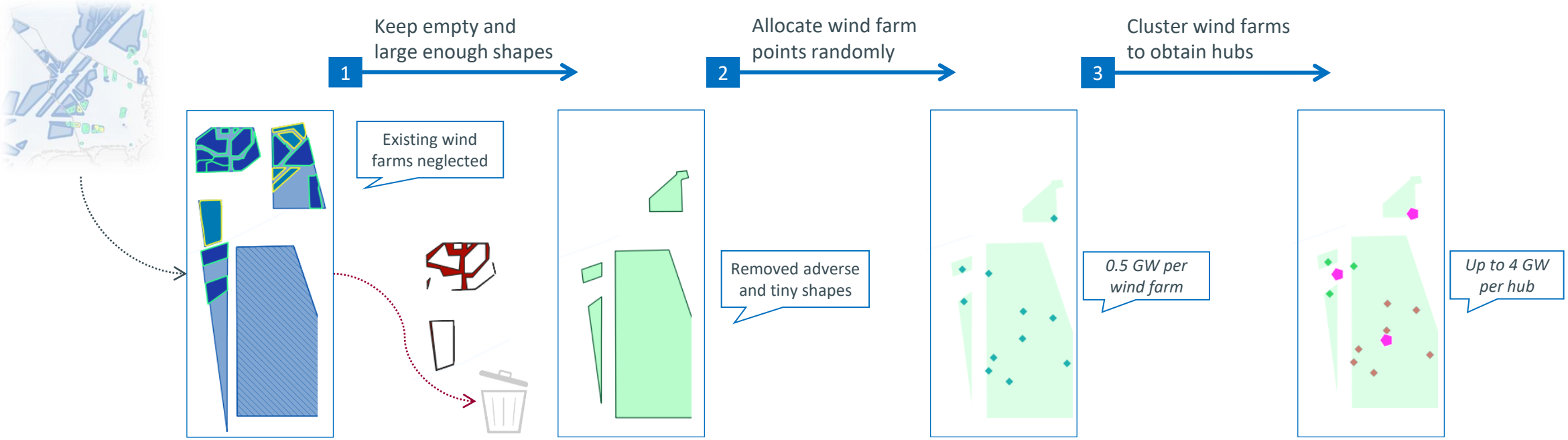
II Point allocation — QGIS

III Link creation — QGIS

IV Complexity reduction — pgRouting

https://qgis.org/en/site/ version 3.26.1 with python version 3.9.5
https://pgrouting.org/

Point allocation – a computation help to locate wind power capacities at sea

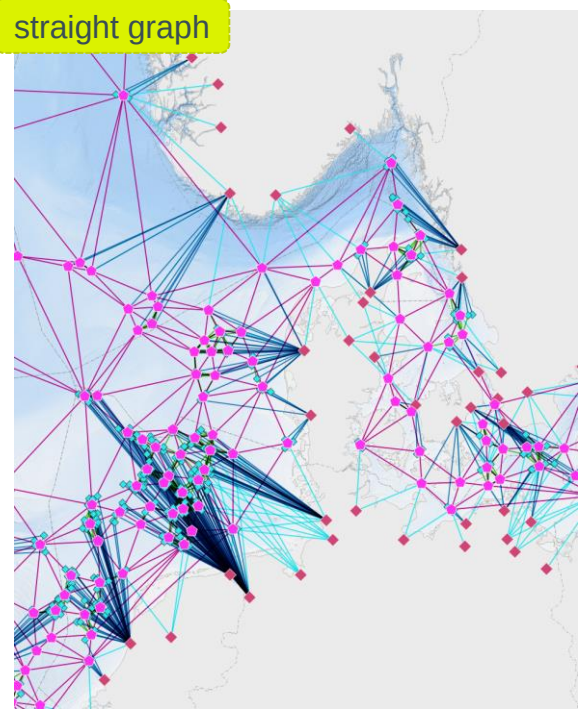


Wind farm allocation respects national capacity targets, common power densities, wind farm sizes and cluster sizes

With: Svendsen 2013, Fliegner 2022

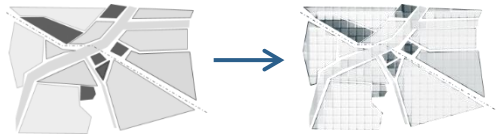
Graph refinement – make the search graph more accurate

straight graph



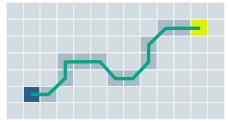
Multi-Criteria-Analysis

1 Rasterization



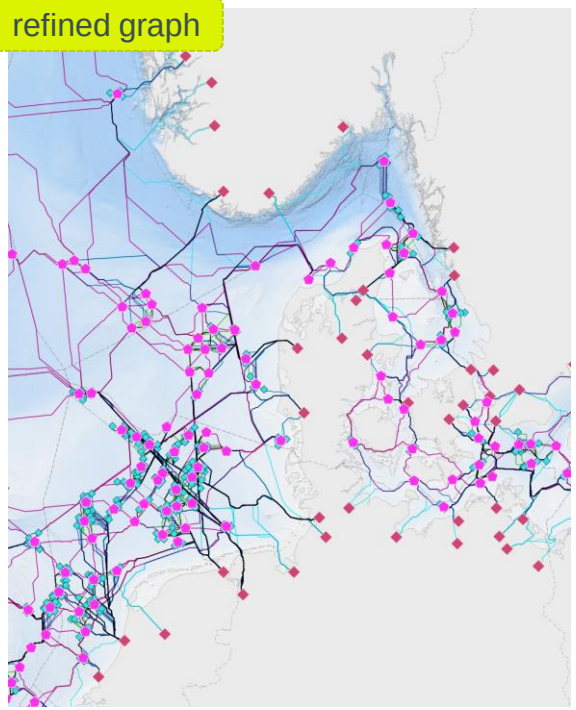
2 Advanced hierarchy process

3 Least cost path search



n *for all graph elements*

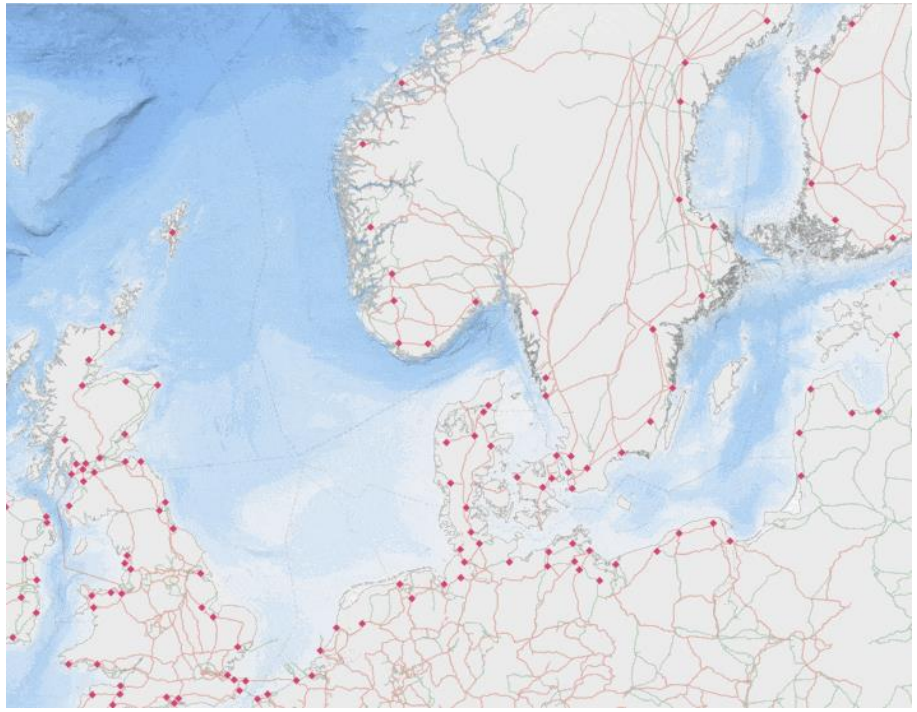
refined graph



Key input for graph refinement is the maritime spatial planning in all countries

With: de Lima 2016, Göpel 2013

Complexity reduction – prepare the graph for modelling



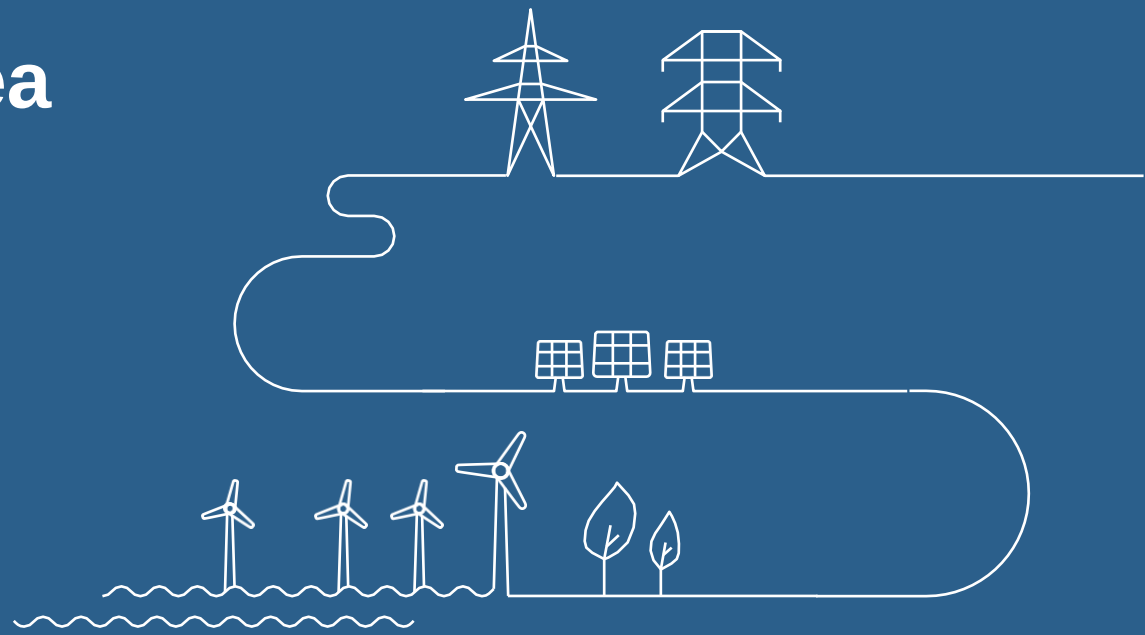
Exemplary search queries

- K-shortest paths from A to B (via C)
- Service Area Analysis
- Minimum Spanning Tree
- *… or any other desired navigation query*

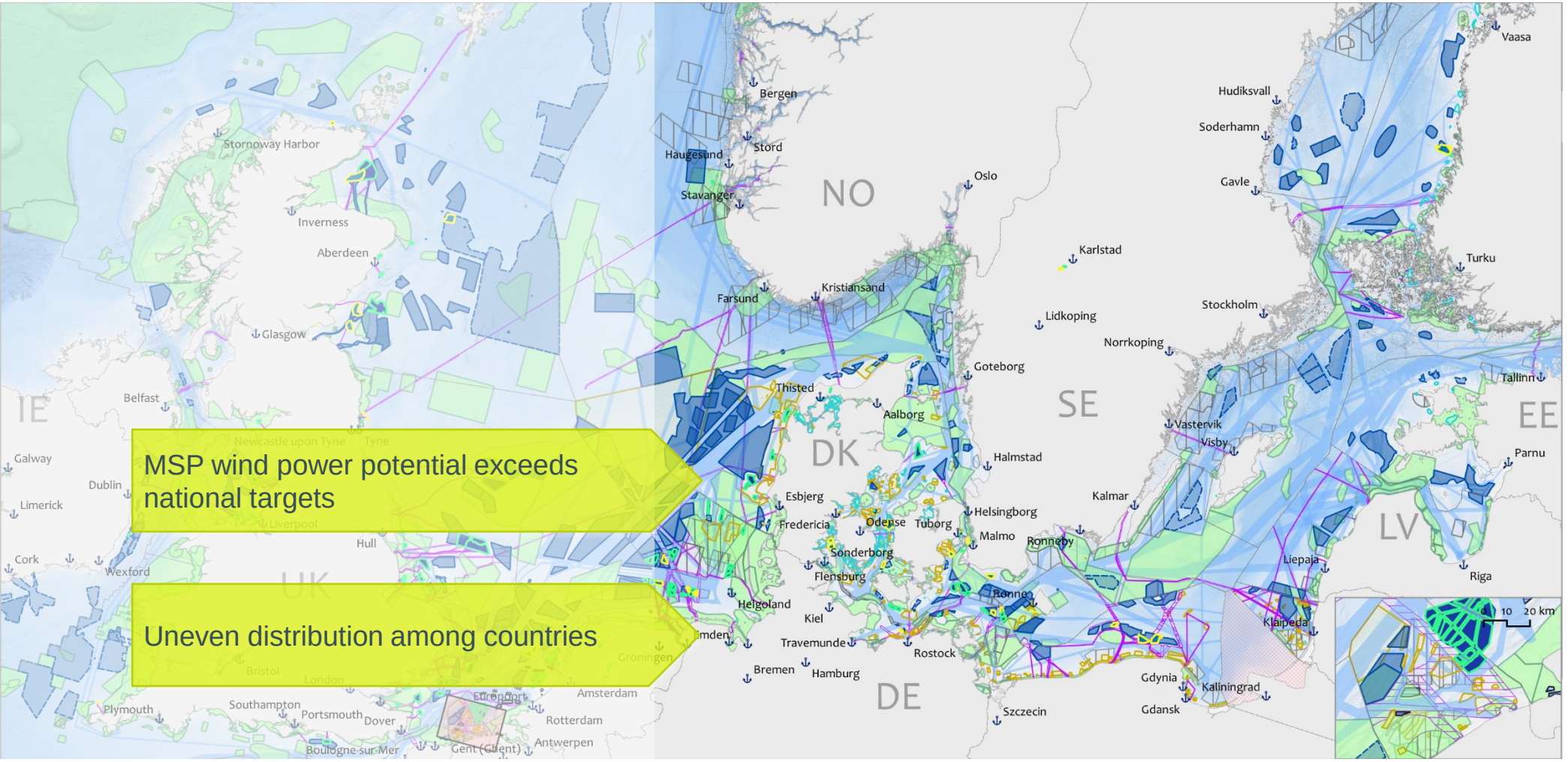
Complexity reduction is achieved via search queries on the graph.

The case of Baltic and North Sea

Application of the GIS methodology



The sea space is managed intensively



Maritime Spatial Planning in Baltic and North Sea

Starting point for GIS analysis on wind farm allocation, clustering and search graph build up

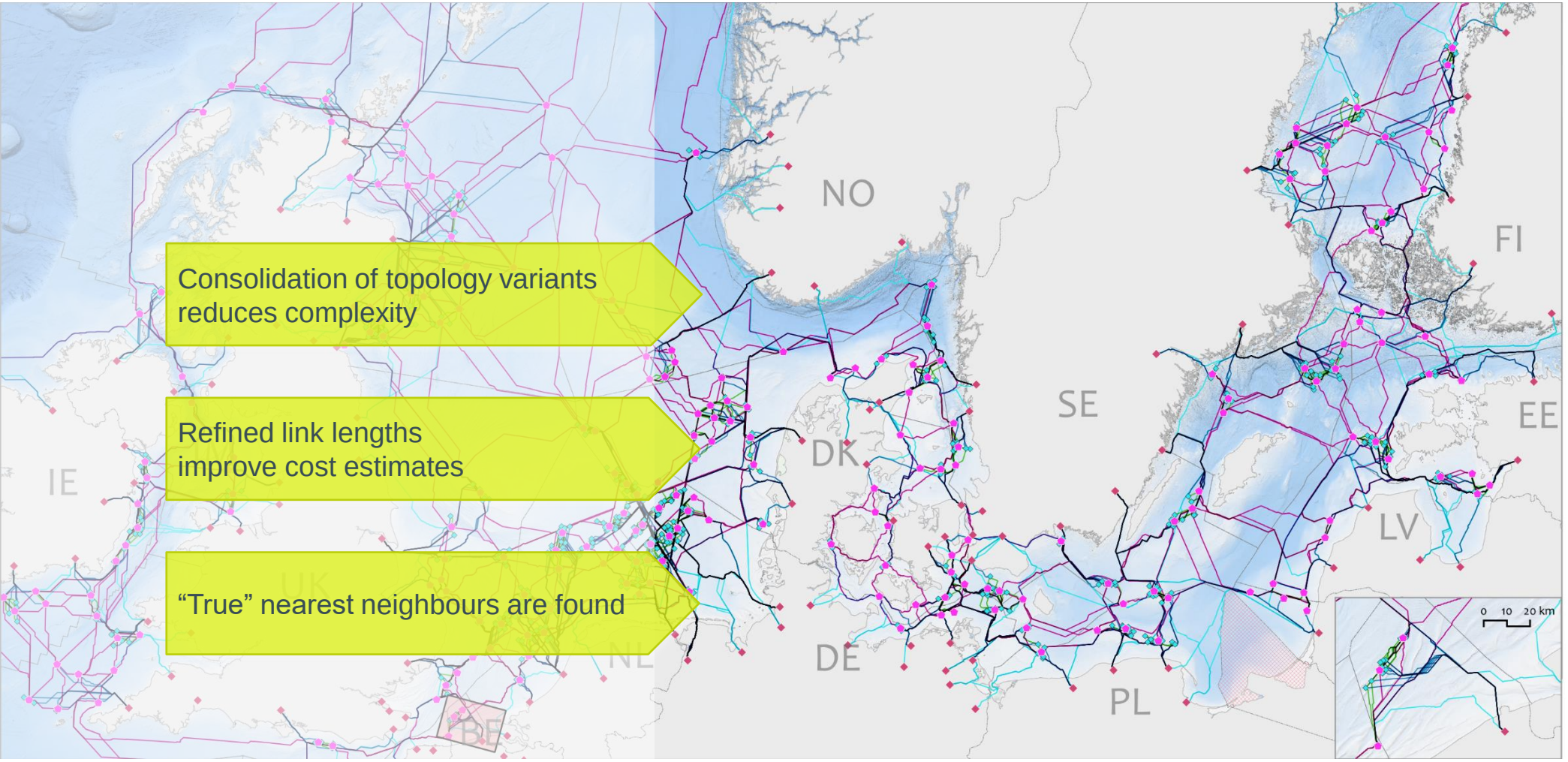
Commissioned wind farms
- before 2023
- up til 2026

Maritime Spatial Planning
- Wind Power
- Wind Power investigation
- Infrastructure Corridor
- Shipping
- Anchorage
- Natural and Cultural Conservation
- Military
- Aquaculture
- Sand, Material, Oil extraction
- Major Sea Ports

Data: © OpenStreetMap contributors; 4COffshore; National Maritime Spatial Planning as of 05/2022; EMODnet Digital Bathymetry (DTM); made with Natural Earth

Source: Own analysis based on national maritime spatial planning data

Refined search graph reduces uncertainty in the analysis



Search Graph Baltic & North Sea

Network of potential transmission paths to realise hybrid interconnectors, offshore hubs and radial connections

Network Points
- HUB
- OWF
- POC

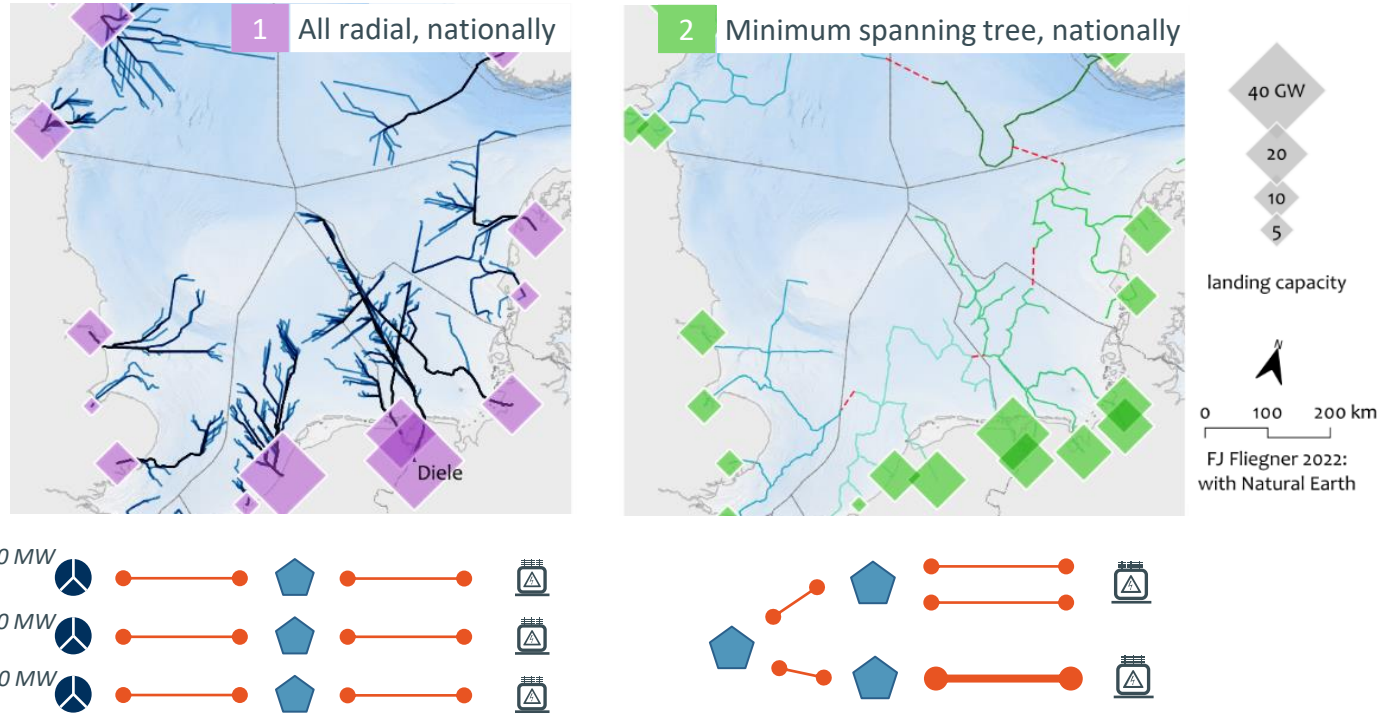
Search Graph
- HUBchain
- HUBradial
- HUBspoke
- OWFradial

Data: © OpenStreetMap contributors; National Maritime Spatial Planning as of 05/2022; EMODnet Digital Bathymetry (DTM); made with Natural Earth

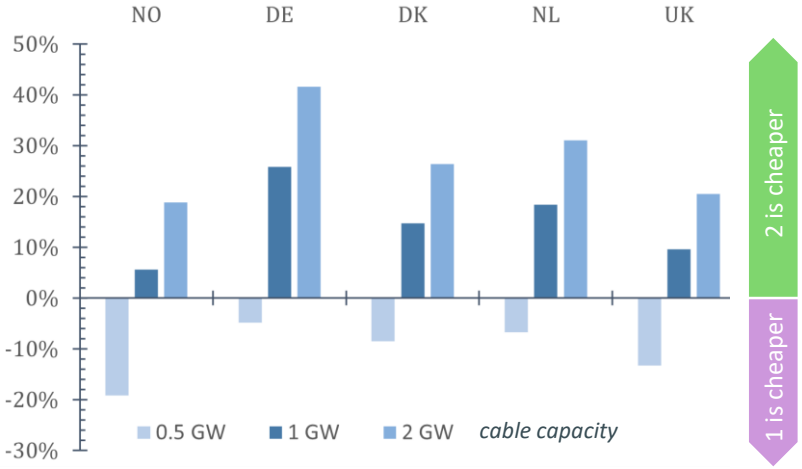
Search graph does neither denote any forecast on likelihood nor preference for offshore grid topologies of the future

Connecting all future wind farms radially is suboptimal

Landing capacity distribution among near shore substations



Cost difference of 1 vs. 2



Scenario: Wind farm capacity equivalent to national 2050 pledges is allocated in the sea according to MSP areas and connected to nearshore substations via refined search graph

Impact of model parametrisation

Focus

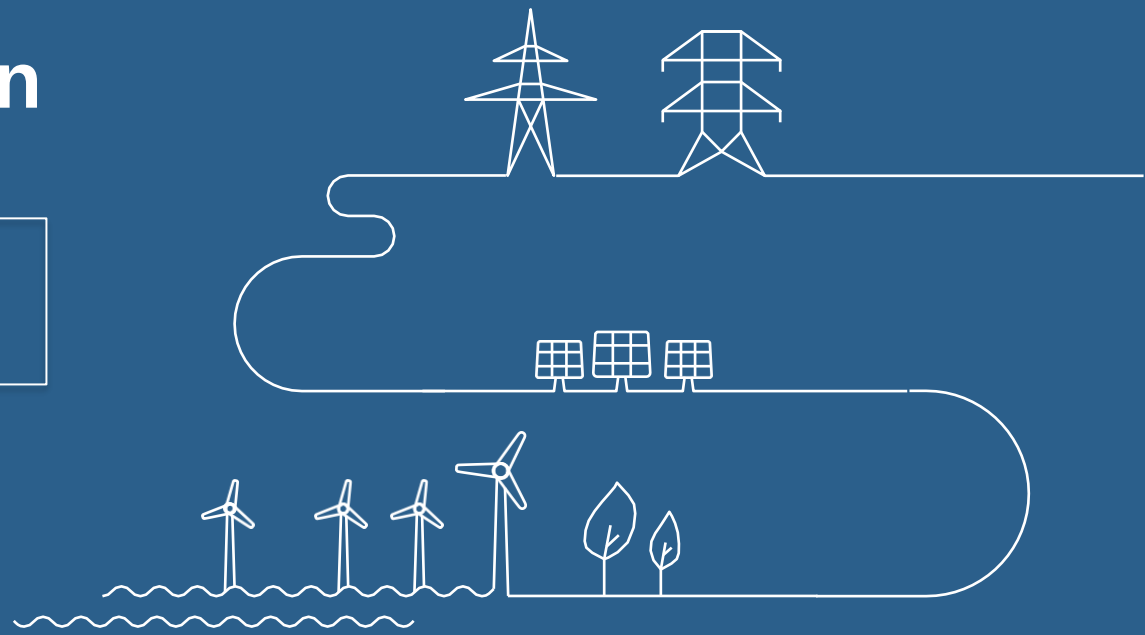
Resolution of penalty cost raster

Selection and importance of maritime obstacles

Set of assumed (new and legacy) onshore substations

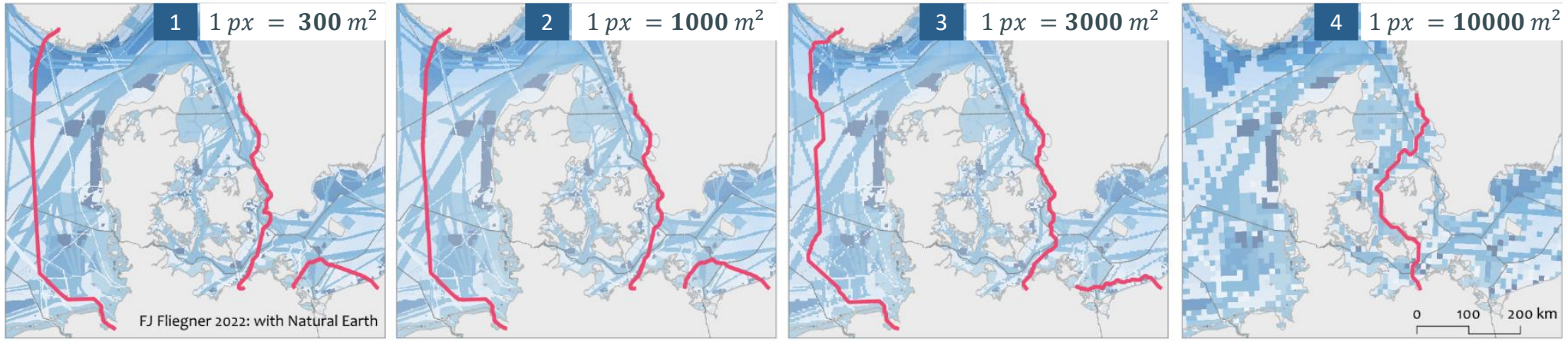
Cost parameters (esp. platforms relative to cables)

Quality of maritime spatial planning data



Search graph resolution is a trade-off between accuracy and model run time

Impact of raster resolution on least-cost-path search

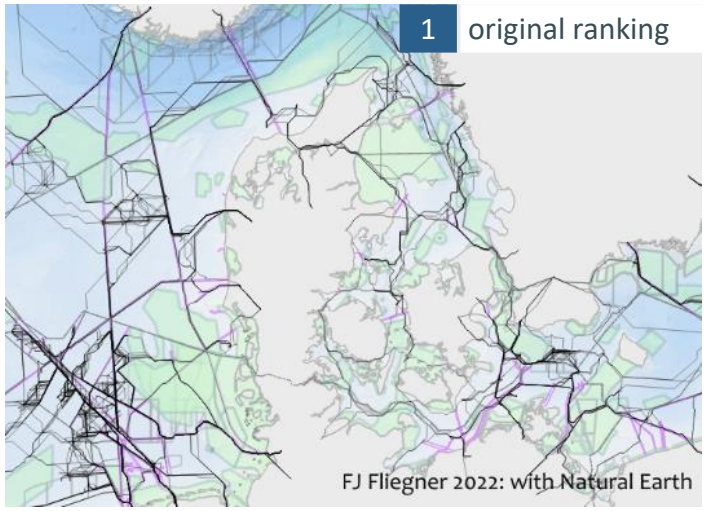


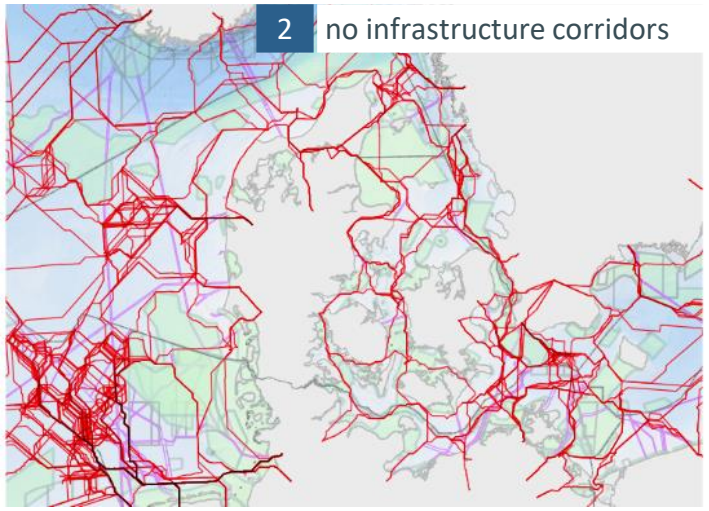
Chosen in this analysis

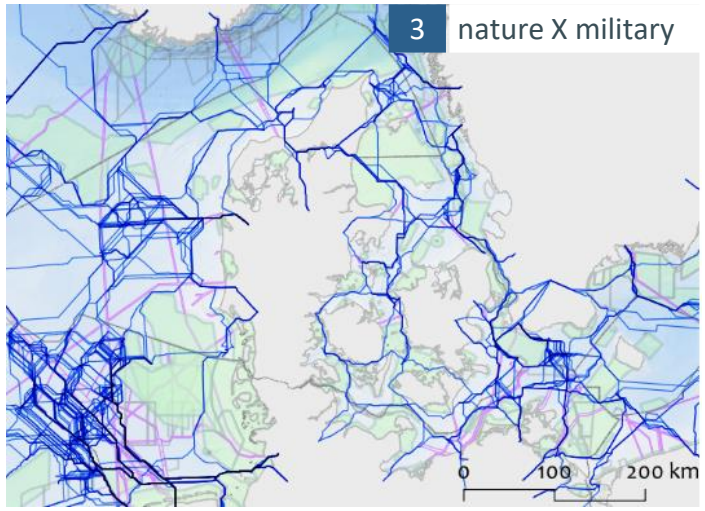
An optimal raster resolution is found between 300 and 1000 m² per pixel

Data quality and consistency is crucial for the proposed workflow

Impact of MSP category ranking on least-cost-path search



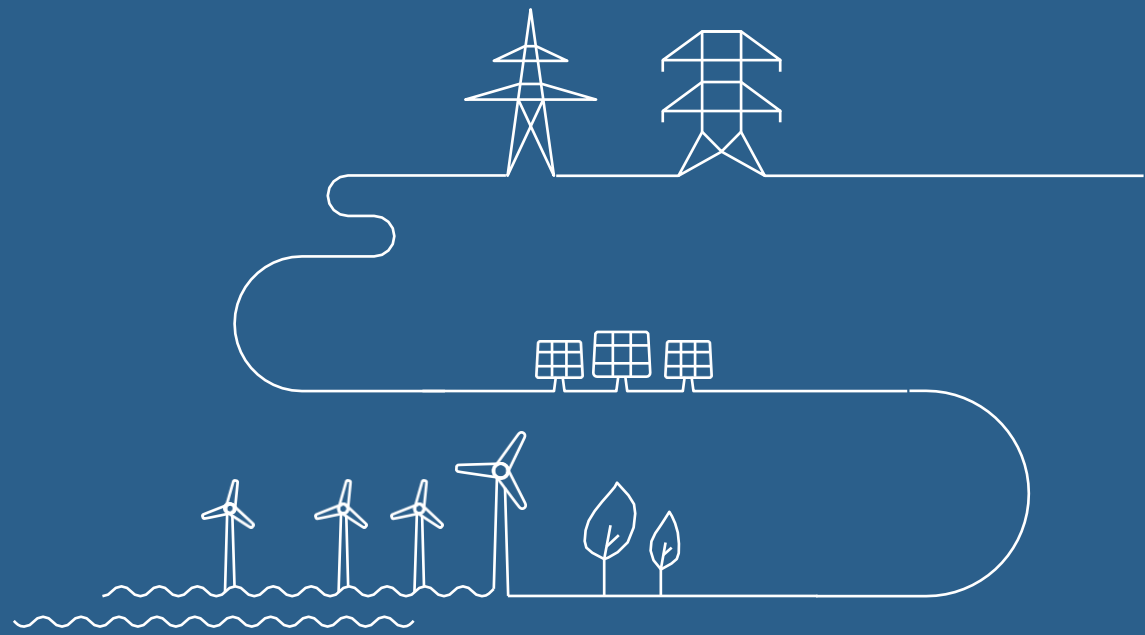




Designation and knowledge of infrastructure corridors influences the search graph topology the most

Looking ahead

Conclusions from GIS analysis and next steps



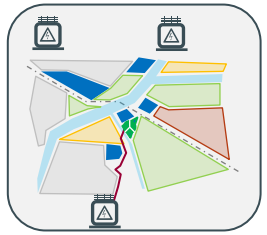
The next generation offshore grid…

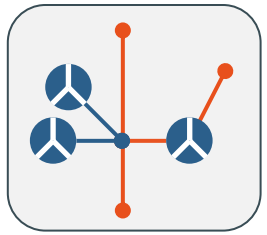
… faces an unprecedented number of wind farms to be connected…

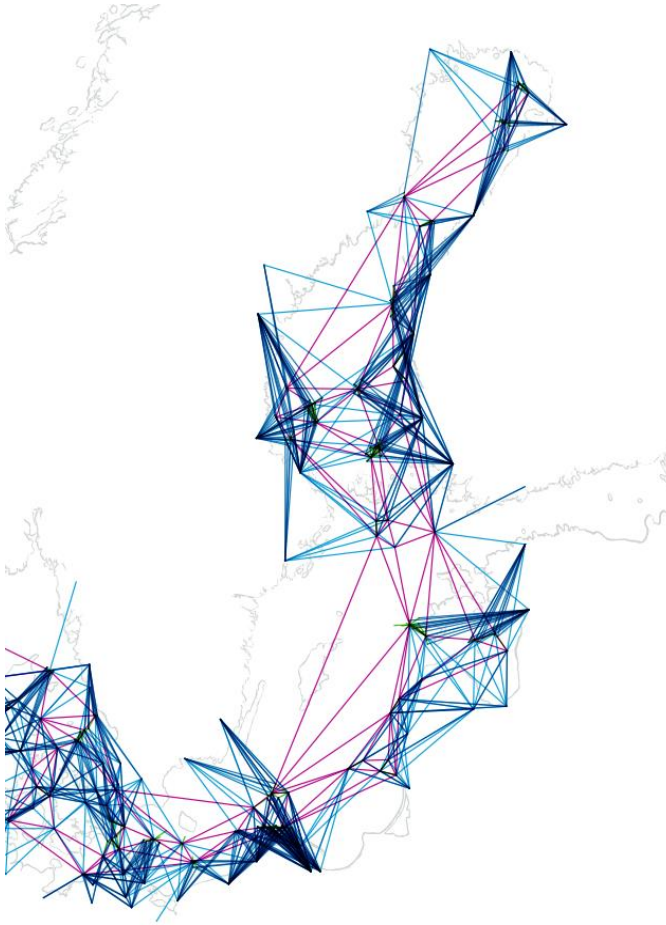
… evolves in a heavily managed sea space…

… rendering its optimisation a complex problem …

… where a GIS analysis can provide a high-resolution, yet tangible search graph to organize the solution space.

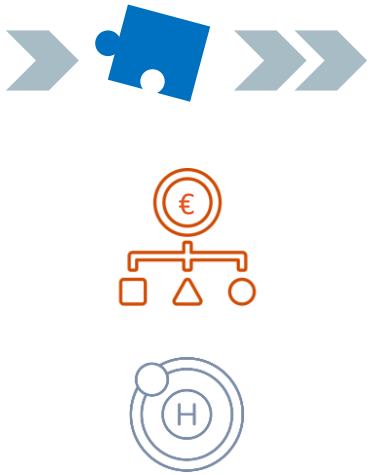






Looking ahead

- “True” societal value of bundled transmission paths is found in subsequent market and grid studies
- Multi Criteria Analysis is highly sensitive to parametrization and scope
- The future is (not just) electric: coupling with offshore legacy assets, hydrogen or CCS infrastructure are possible extensions



In a next step the GIS analysis will be coupled with an optimization problem to demonstrate its performance in an energy system model

References

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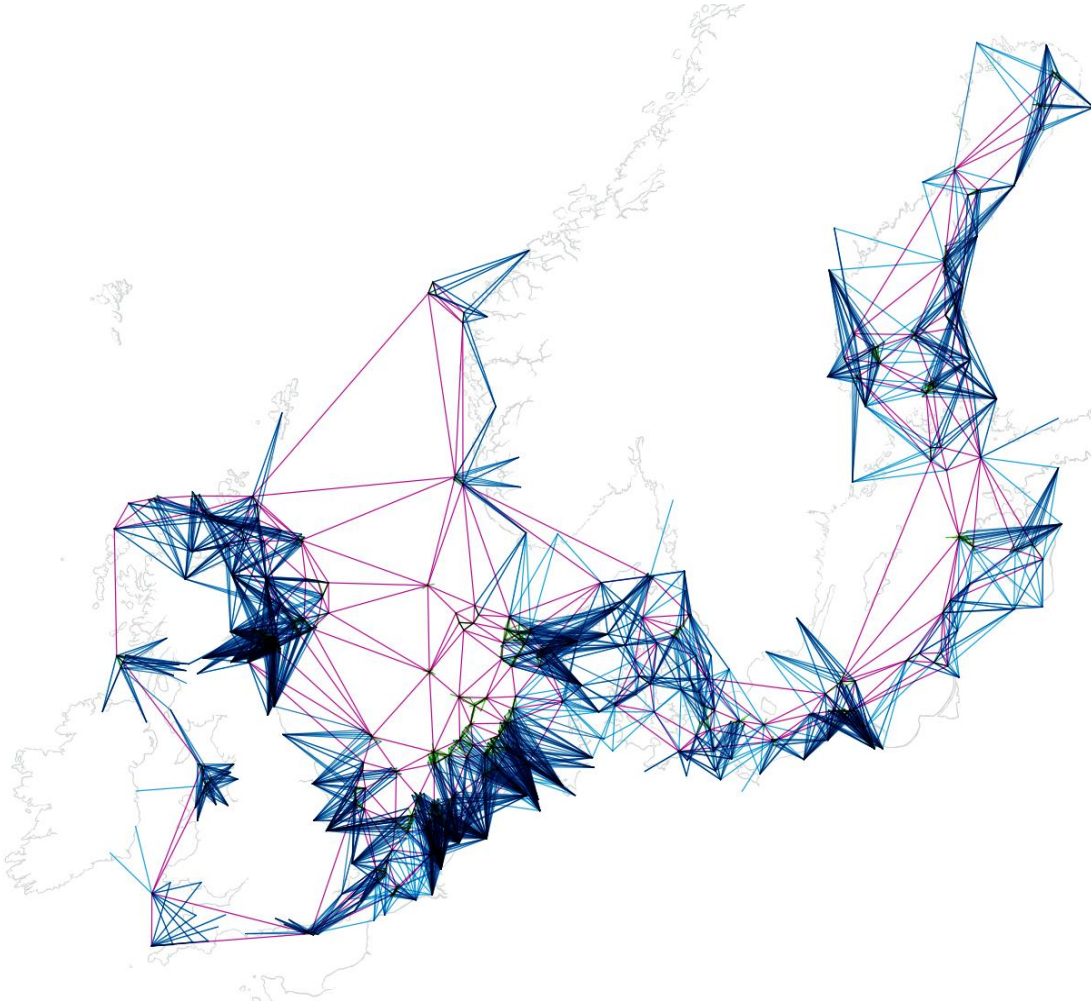
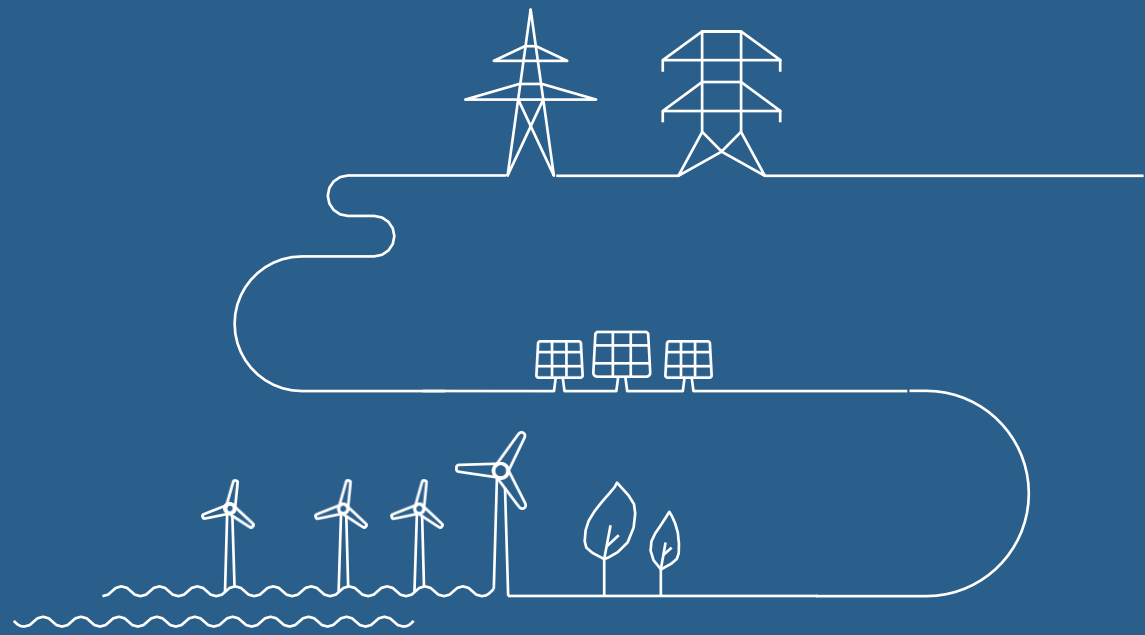
Felix Jakob Fliegner
Chair of Energy Economics, TU Dresden | System of the Future, 50Hertz

FelixJakob.Fliegner@50hertz.com
https://de.linkedin.com/in/fliegner

50Hertz Transmission GmbH
Heidestraße 2 • 10557 Berlin



Backup



Feasibility rules for link creation

process	parameter	unit	value	comment
Point allocation	Area-to-perimeter ratio	%	60	Obtained by manual testing
	Power estimate derating	%	-10	Obtained from empirical studies of existing wind farms
	OWF unit size	GW	0.5	Arbitrary selection, small enough to achieve high granularity
	Min OWF distance	km	10	Estimated from existing wind farm footprints
	DBSCAN threshold	km	30	Derived from maximum spoke cable length
	heap size threshold	GW	4	Arbitrary selection high enough to achieve some consolidation effect
	OWF power density	MW/km²	5-16	Obtained from empirical studies of existing wind farms
Link creation	max no. of OWFradial	1/OWF	3	Arbitrary selection
	max length of HUBspoke	km	30	Derived from existing hub dimensions today
	max length of chains and radials	km	unlimited	Under the assumption of DC technology

Advanced hierarchy process parameters for least cost path search

	base case	no infra	natureX military
AHP scale	linear	linear	linear
Infrastructure Corridor	2%	/	/
Open sea	3%	3%	3%
Wind Power Development	4%	4%	4%
Aquaculture	4%	4%	4%
Natural conservation reserved	5%	5%	17%
Natural conservation	7%	7%	15%
Shipping	9%	9%	6%
Military reserved	13%	13%	9%
Military	16%	16%	7%
Anchorage, Extraction, etc.	37%	39%	35%
Landcover and Russian areas	inf.	inf.	inf.

AHP excel tool as implemented by Goepel 2013 was used for the analysis: New AHP Excel template with multiple inputs – BPMSG