Max Planck Institute for Biogeochemistry

DTU

Agora Energiewende

Making the most of offshore wind

Re-Evaluating the Potential of Offshore Wind in the German North Sea

Matthias Deutsch, Jake Badger, Axel Kleidon

Agora Energiewende – Who we are

Think Tank with more than 40 Experts

Independent and non-partisan

Project duration 2012 – 2021
Financed by Mercator Foundation & European Climate Foundation

Mission: How do we make the energy transition in Germany a success story?

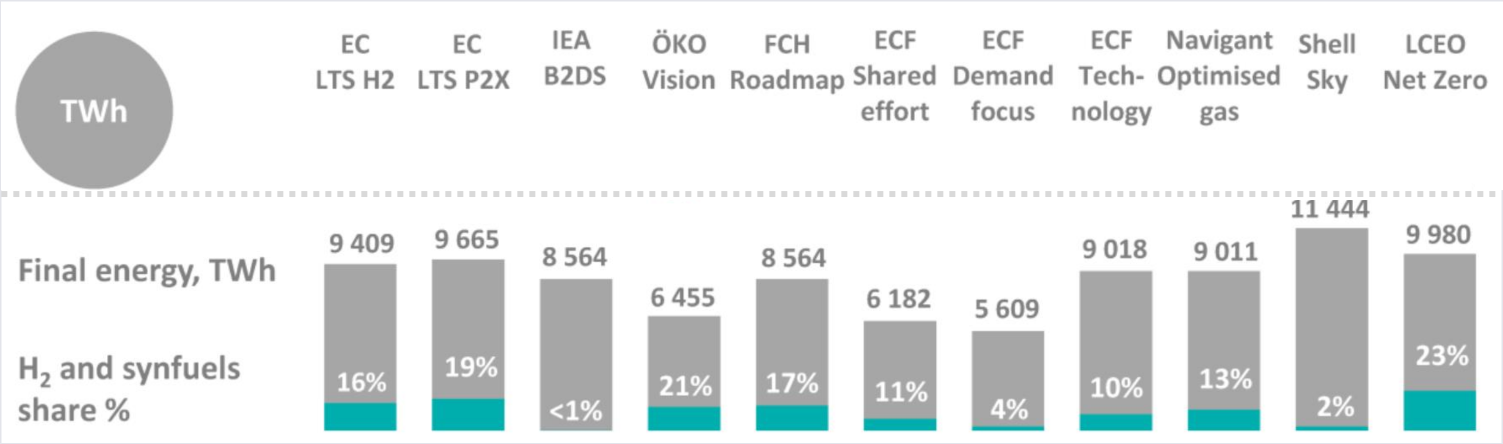
Methods: Analyzing, assessing, understanding, discussing, putting forward proposals, Council of Agora

Outline

1.	Introduction: Hydrogen and offshore wind
2.	Analysis by DTU and MPI
3.	Conclusions drawn by Agora Energiewende
4.	Questions and answers

Hydrogen and derived fuels add up to between 10% and 23% of the 2050 EU final energy consumption in most scenarios…

Hydrogen and derived fuels for energy use *



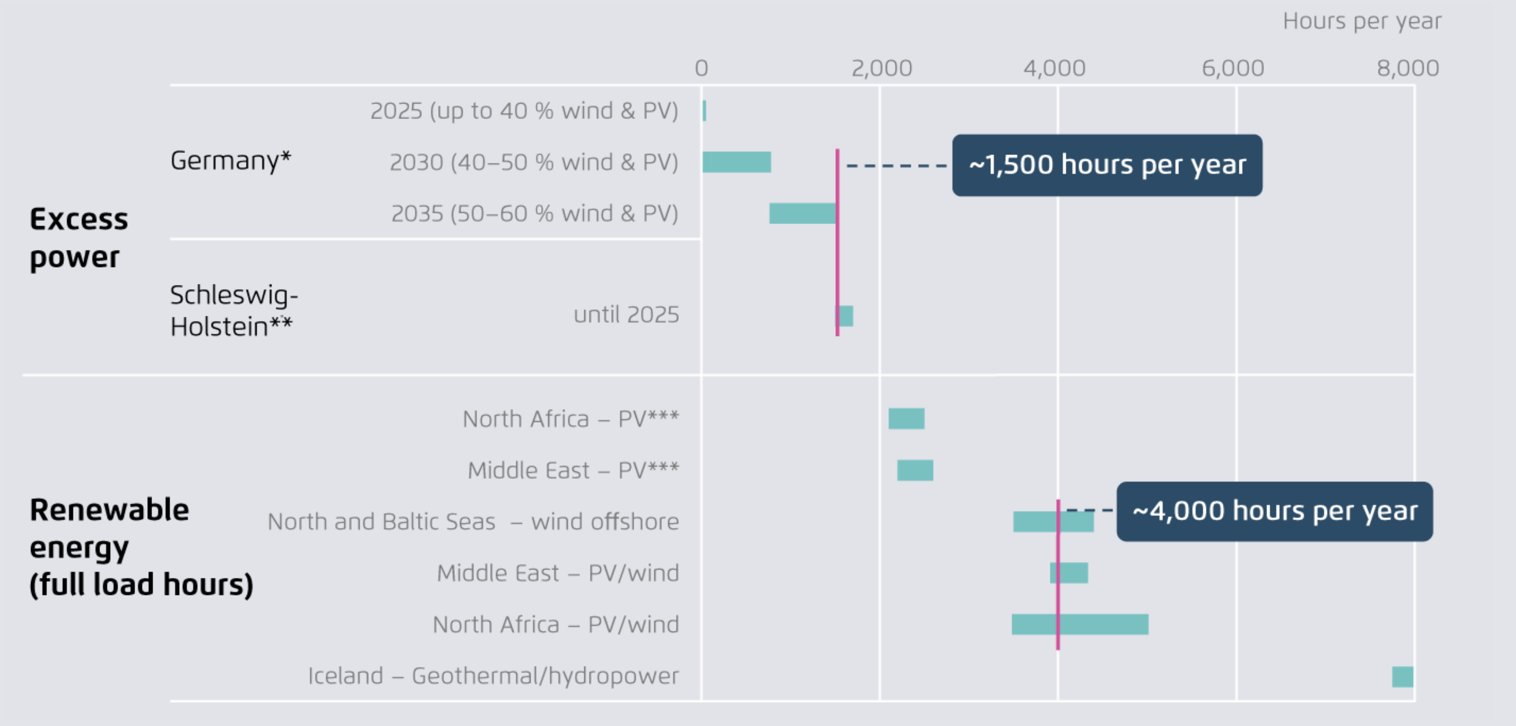
** Hydrogen for non-energy uses is not included*

JRC (2019): Hydrogen use in EU decarbonisation scenarios, adjusted

- → … examined by the European Commission's Joint Research Center.
- → Those percentages represent between **~700 and 2300 TWh** of hydrogen and derived fuels.

Electrolysis for green hydrogen needs high full-load hours (> 3,000-4,000 h/a) and inexpensive renewable electricity.

Hours per year



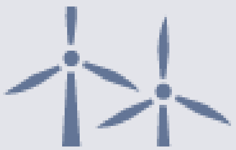
Agora Verkehrswende & Agora Energiewende (2018): The future cost of electricity-based synthetic fuels

- „**Excess power**“ in Germany with < 2,000 hours/year at low prices is insufficient.
- Regarding dedicated renewable energy plants for hydrogen production, MENA countries with great PV and onshore wind potential compete with **offshore wind in Europe.**

Coupling offshore wind with electrolysers

Different configurations

	Offshore		Onshore	Sample projects
Renewable electricity	• Electric grid connection		• Electrolysis	• Gigastack, UK • NorthH2, NL
	• Electrolysis	• Shipped to shore • Piped to shore		• PosHYdon, NL



Agora Energiewende (2020)

Project overview: Making the Most of Offshore Wind

Commissioned by: Agora Energiewende and Agora Verkehrswende

Partners: Max-Planck-Institute for Biogeochemistry (MPI-BGC)
Technical University of Denmark, Department of Wind Energy (DTU)

Question: How many full-load hours can offshore wind reach assuming a huge expansion in the German North Sea until 2050?

Background: Climate target scenarios for Germany typically assume around 4000 full load hrs

Methodology:

→ Simulations of installed offshore wind capacity with two different physics-based approaches that include how the atmosphere reacts

→ **MPI:** Box model implemented in a spreadsheet ("KEBA")

→ **DTU:** Numerical Weather Research and Forecast model (WRF-EWP), running on a computer cluster

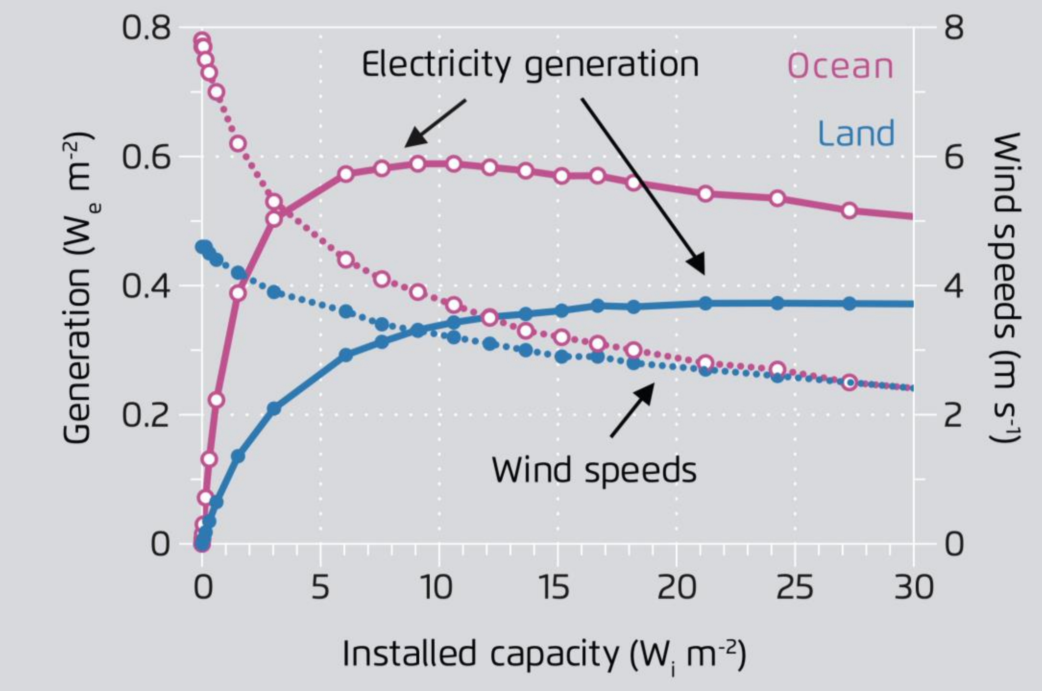
Download:

- Publication
- Feed-in time series
- KEBA model
- Slide deck
- Webinar

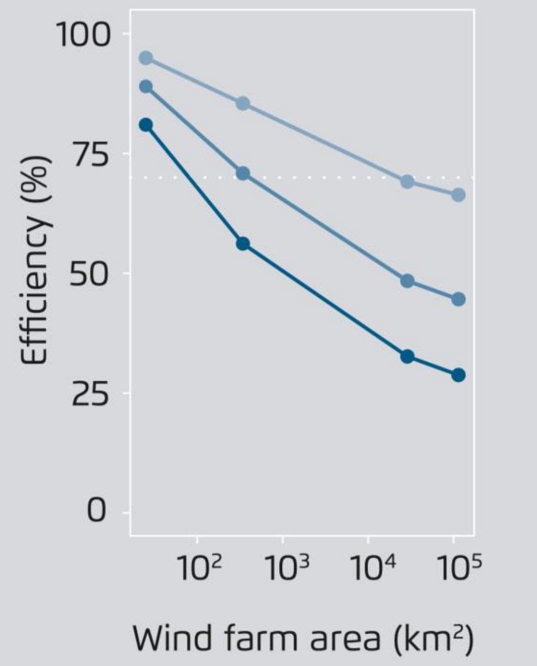
Analysis

by DTU and MPI

Motivation



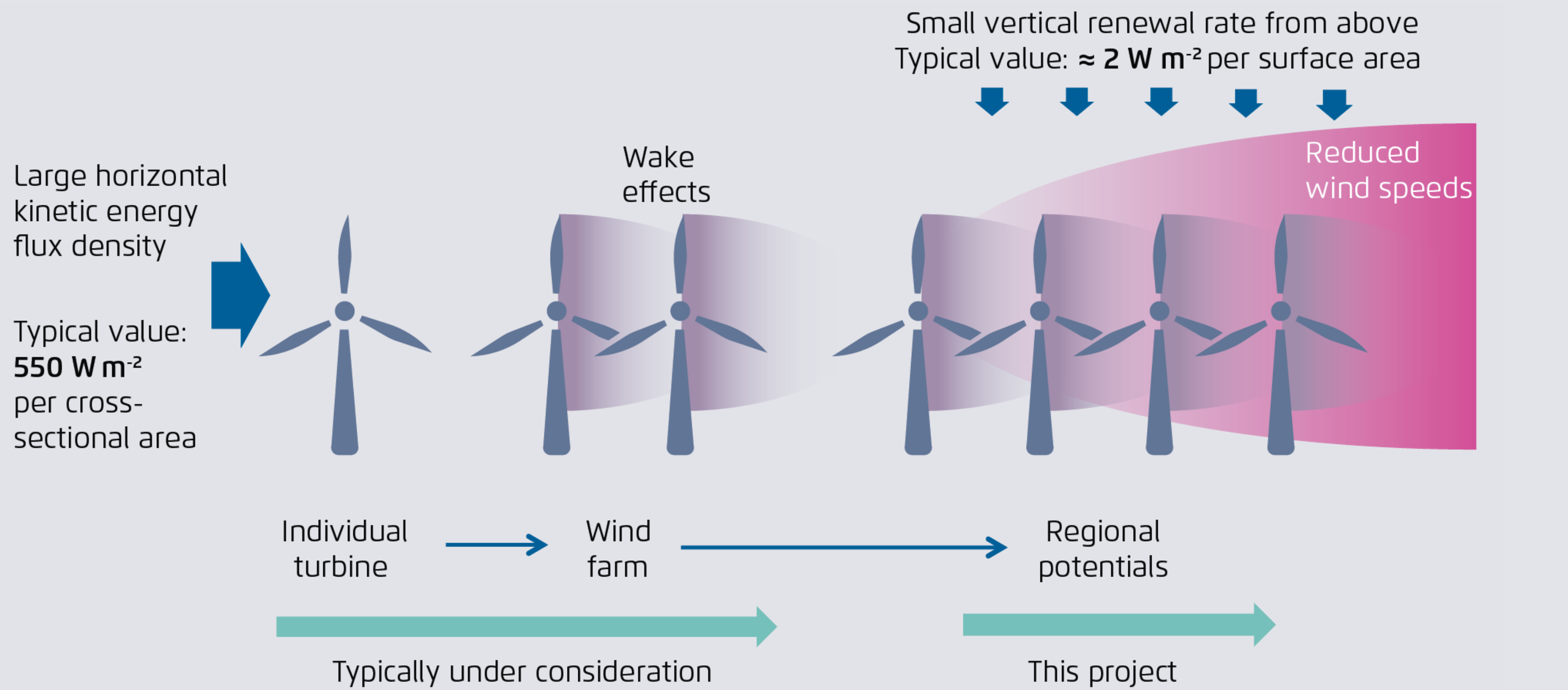
Miller und Kleidon (2016) *PNAS*



Volker et al. (2017) *ERL*

→ Climate model simulations show that many turbines reduce wind speeds, turbine efficiencies, and wind energy resource potentials

More than wakes…



Present scales of wind farm development	Future scales of wind farm development
Well observed	Not yet observed
Simulated by engineering models	Simulated by physics-based models

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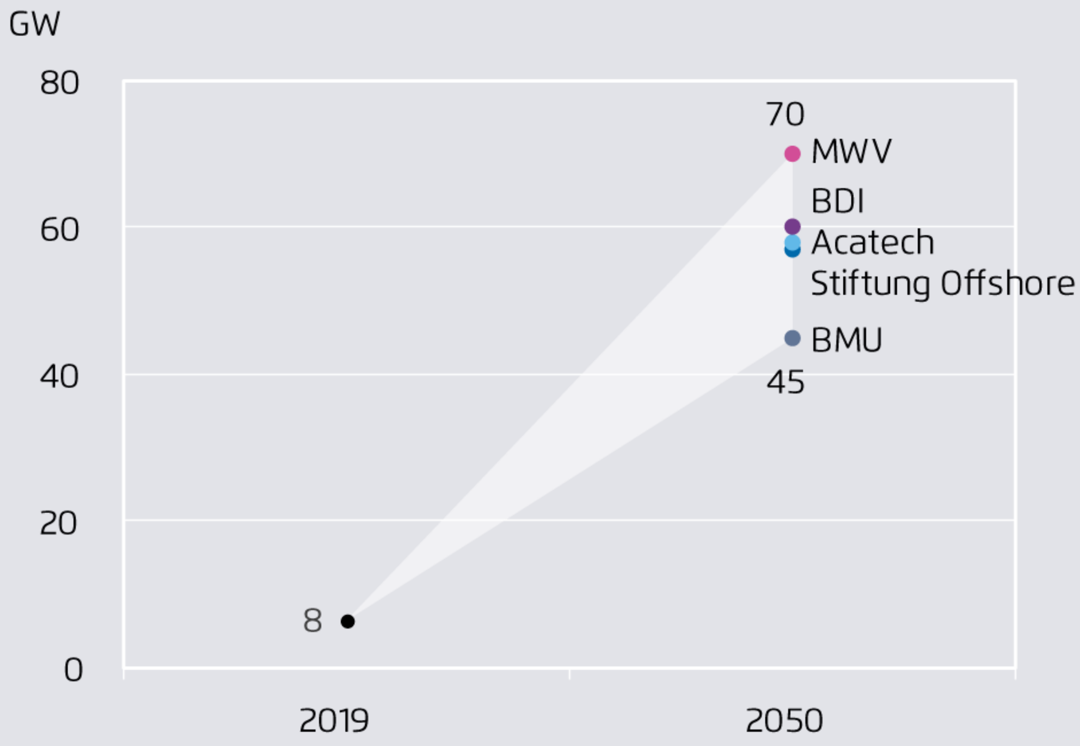
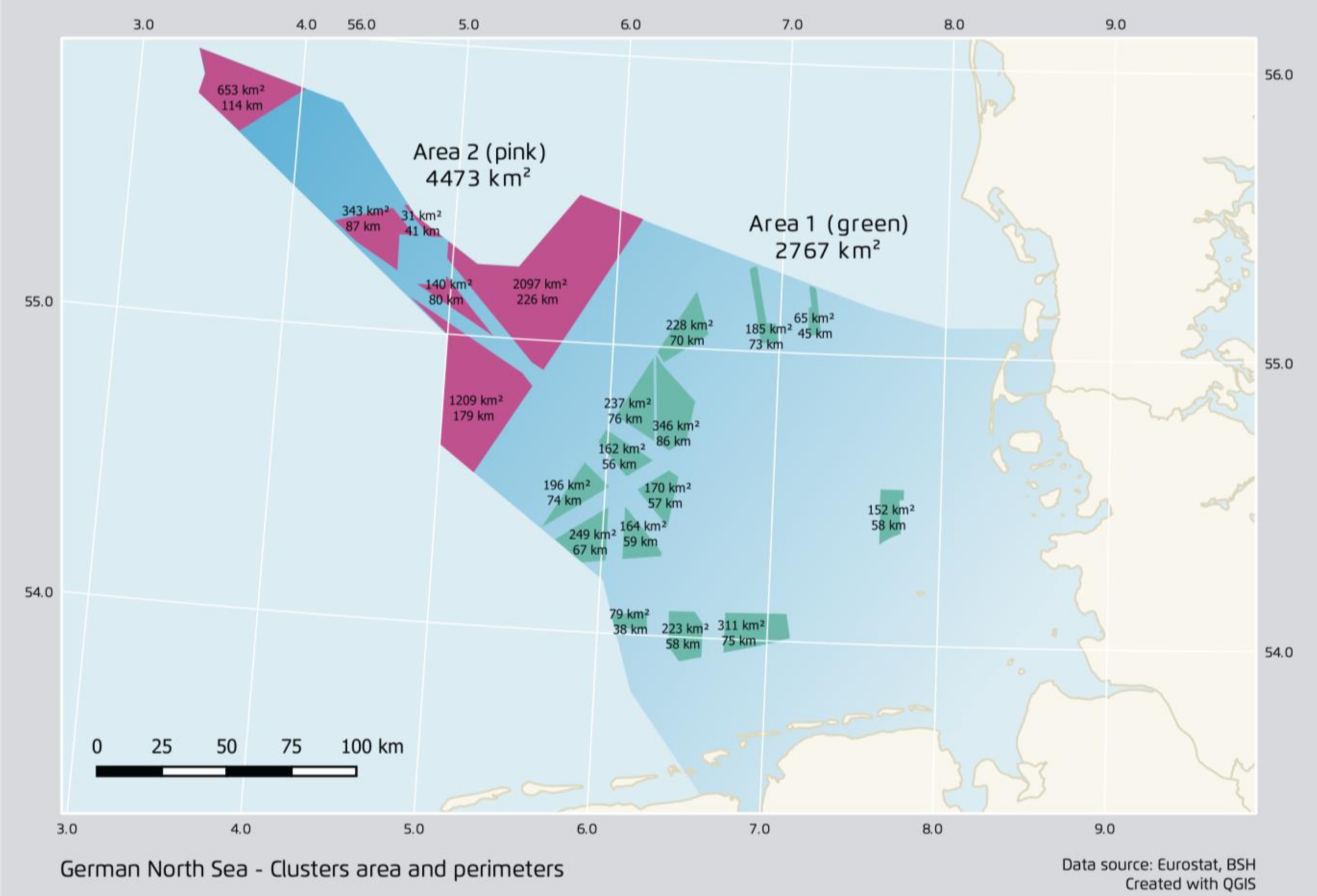
Scenarios for 2050



Acatech et al. (2017), Agora Energiewende (2020), BDI (2018), BMU (2015), MWV (2018), Stiftung Offshore (2017)

- → Scenarios for 2050 expect 45 – 70 GW of offshore installed capacity, yielding 200 – 280 TWh/a.
- → *To which extent are yields likely to be reduced due to reduced wind speeds?*

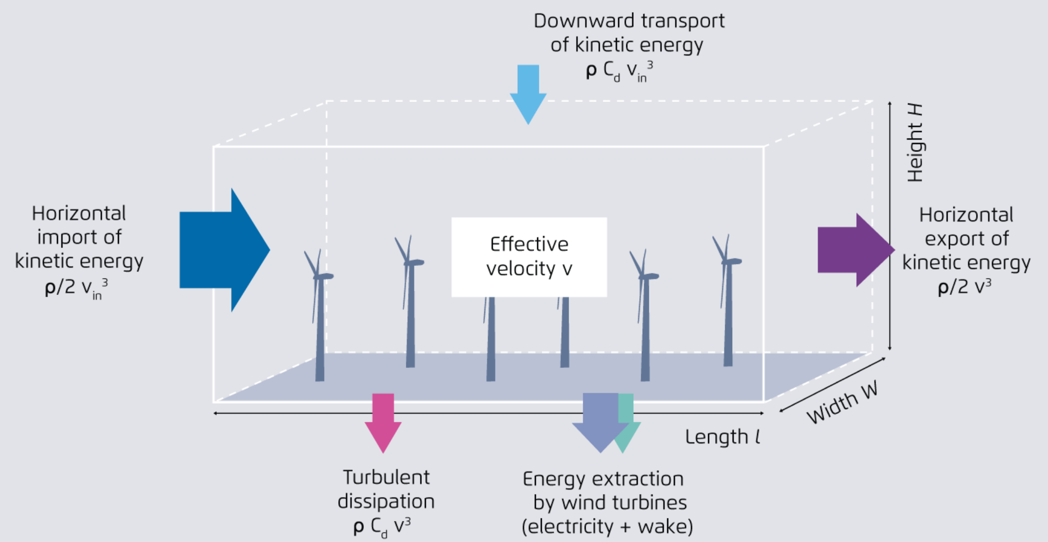
Formulation of the Scenarios



- → Focus on EEZ of the German Bight
- → Consideration of possible areas, separated into Area 1 and Area 2
- → Evaluation of different installed capacity densities (5, 7.5, 10, 12.5, 20 MW/km^2)
- → Hypothetical 12 MW turbines
- → Use of “Area 1”, “Area 2”, and both areas (“Area 3”)
- → Yields scenarios of 13.8 – 144.8 GW
- → Current expansion plans focus on “Area 1” only

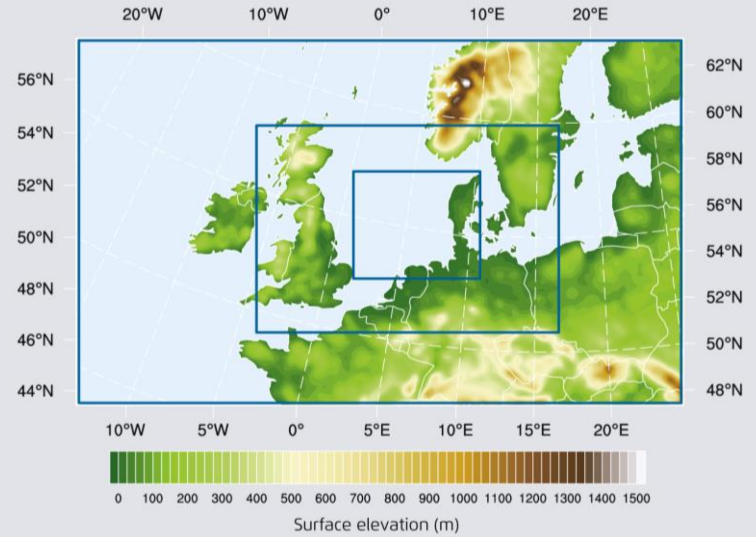
Estimation of Expected Yields

KEBA
Kinetic Energy Balance of the Atmosphere
(MPI)



Spreadsheet, highly aggregated,
uses FINO-1 wind observations for 2004-2015

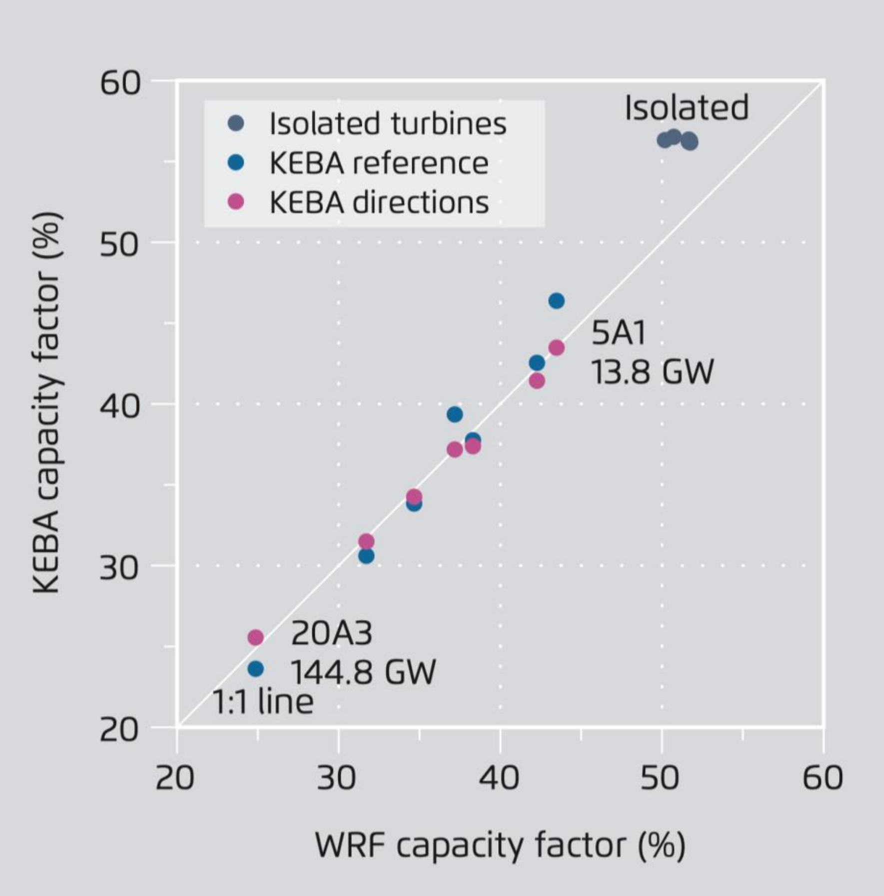
WRF
Weather Research and Forecasting model
(DTU)



Numerical simulation model, highly detailed,
uses ECMWF weather forcing fields for year 2006

Both models are based on physical constraints, specifically the budgeting of kinetic energy
(in contrast to engineering models)

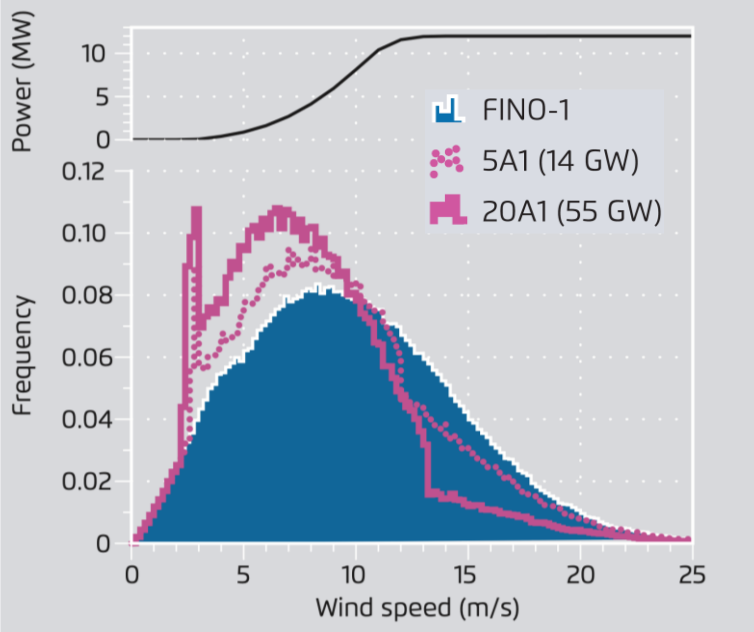
Estimated Yields



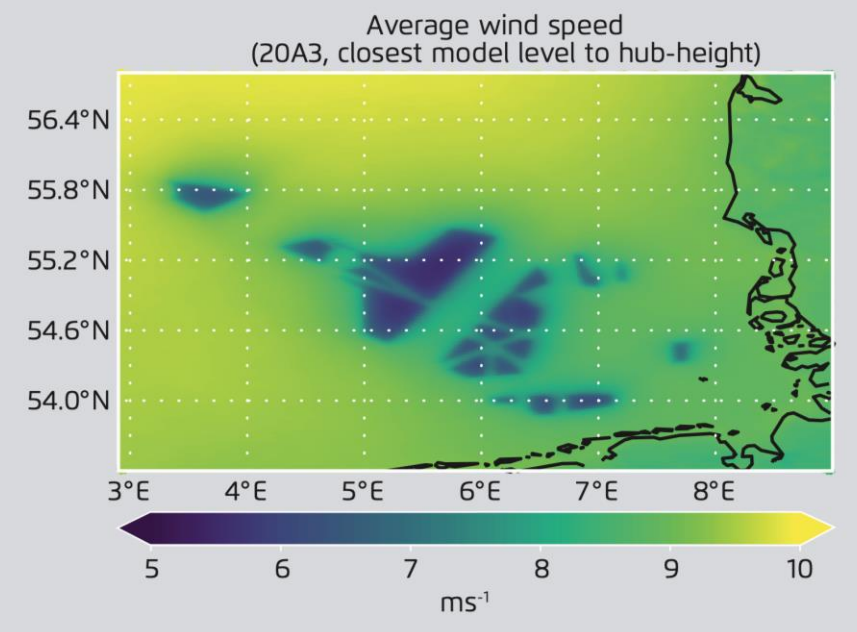
- → Both methods estimate similar reduction in average capacity factors
- → 50% Capacity factor = 4380 full load hours per year
- → From 5A1 to 20A3: 10 times the installed capacity over 2.6 times the area increases yield by factor of 5.3 - 6.0.

Reduction in Winds

KEBA: simulated shift in frequency distribution of wind speeds



WRF: simulated spatial patterns of reduced wind speeds (average)



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Summary of findings

- → Estimation of yields for 13.8 to 144.8 GW of installed capacity in the German Bight
- → Two methods (KEBA, WRF) yield similar estimates
- → Both methods estimate efficiencies of from 82-85% (13.8 GW) to 42-48% (144.8GW).
- → Yield reductions are to be expected in currently considered expansion scenarios for offshore wind energy.

- → Illustrative example:
  - Density: 10 MW/km²
  - Capacity: 28 to 72 GW
  - Full-load hours: ~3400 to ~3000
  - Capacity factor: 39% to 34%

Formulation of scenarios				Results					
	Included areas			With wakes caused by kinetic energy removal					
	Area 1	Area 2		Yield (GW)		Full-load hours [h]		Capacity factor* [%]	
Density (W/m^2 or MW/km^2)	2,767 km^2	4,473 km^2	Installed capacity (GW)	WRF	KEBA	WRF	KEBA	WRF	KEBA
10	x		27.7	10.3	10.9	3,255	3,449	37%	39%
10		x	44.7		16.4		3,216		37%
10	x	x	72.4	25.1	24.5	3,040	2,966	35%	34%

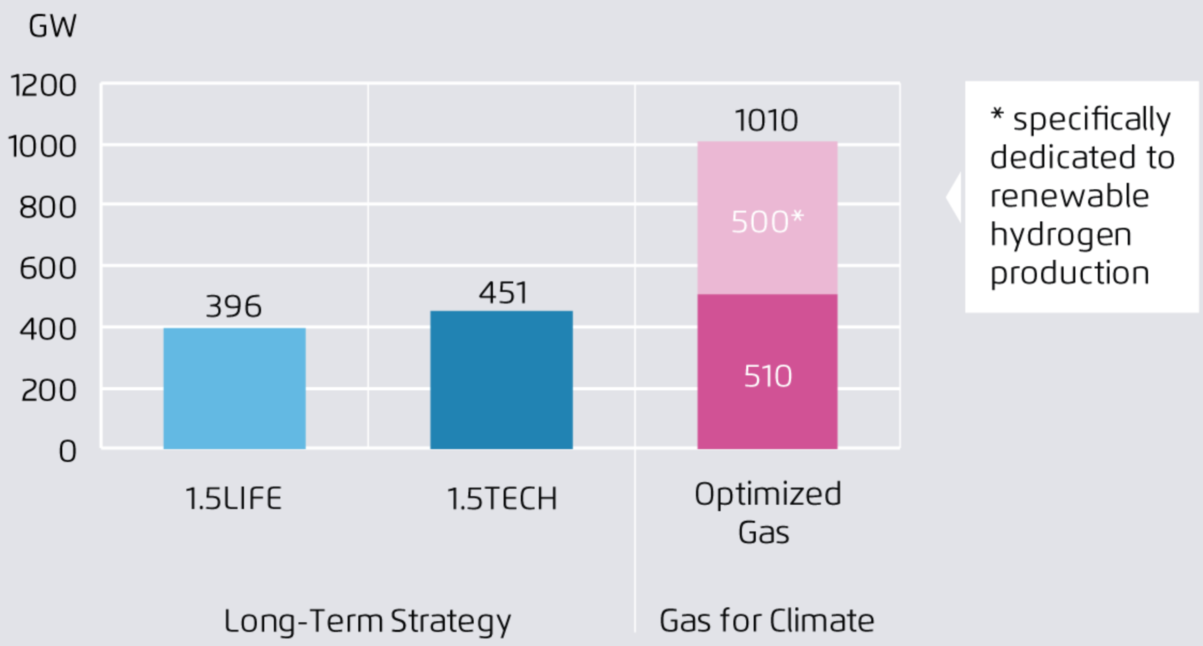
* Other losses not included.

Conclusions drawn

by Agora Energiewende and Agora Verkehrswende

Offshore wind energy, which has an installed capacity potential of up to 1,000 GW, is a key pillar of the European energy transition.

Offshore wind capacity assumed in EU climate target scenarios for 2050 in GW

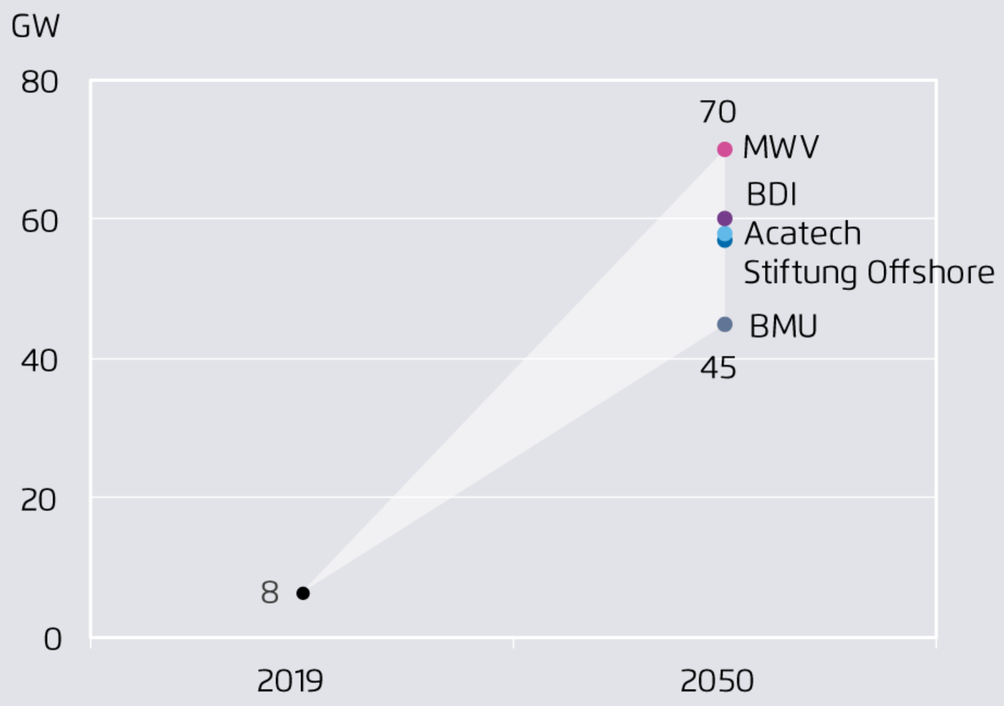


Agora Energiewende & Agora Verkehrswende (2020)

- → The net-zero decarbonization scenarios contained in the European Commission’s **Long-Term Strategy** assume some 400 to 450 GW of offshore wind capacity by 2050.
- → Additional demand of up to 500 GW may be created by dedicating offshore farms to electrolysis for **renewable hydrogen** production.
- → In modelling for the European Commission, offshore wind is assumed to reach **4,000 to 5,000 full-load hours** at very good sites.

Scenarios projecting near climate neutrality by 2050 assume an installed capacity of 50 to 70 GW of offshore wind in Germany.

Installed offshore wind capacity for Germany‘s 95% climate target scenarios in GW

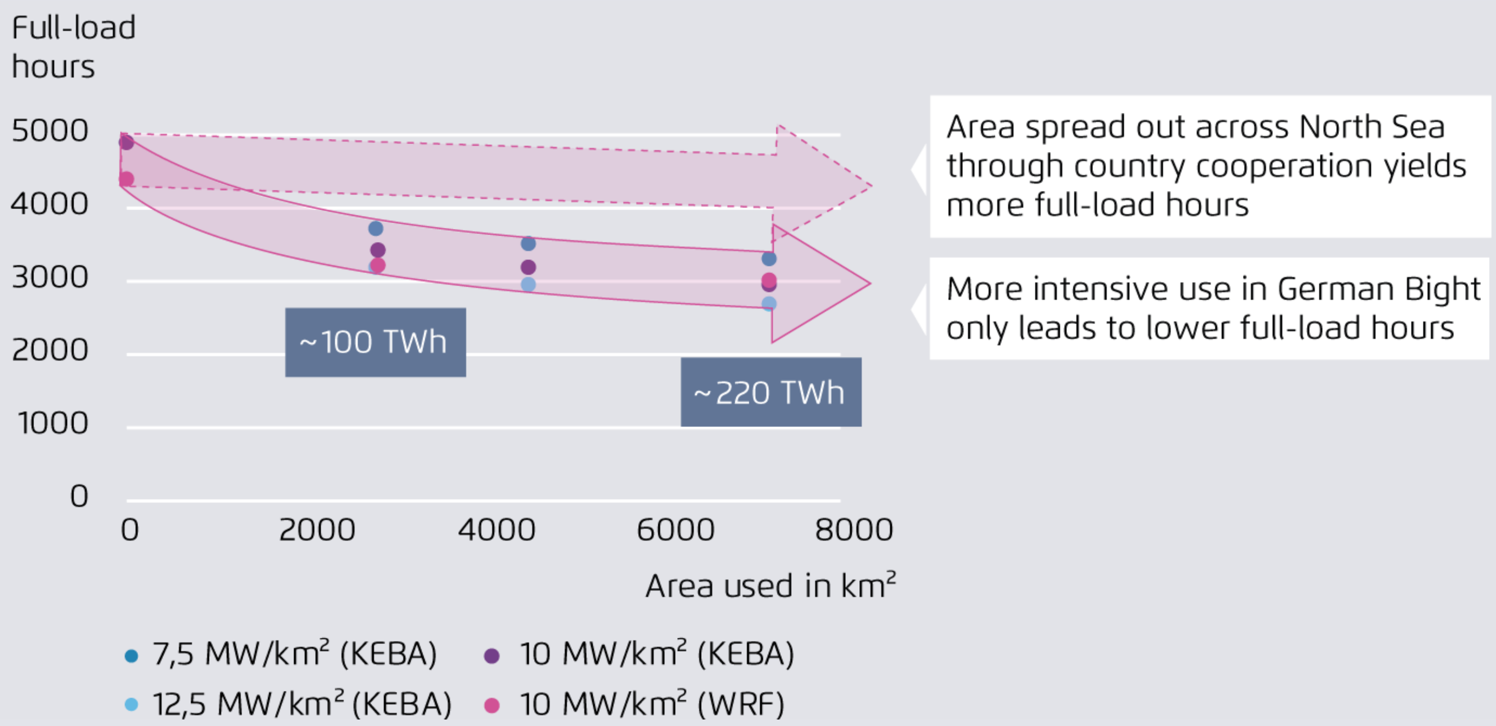


Agora Energiewende & Agora Verkehrswende (2020)

- Generating some **200 to 280 TWh** of electricity per year.
- Given the 8 GW of installed capacity today and current plans for 20 GW by 2030, the **pace of spatial planning** for offshore wind deployment needs to pick up significantly.
- Reaching 20 GW by 2030 implies an increase of the installation rate to **around 1.1 GW per year.**
- After 2030, achieving the higher scenario end of 70 GW would involve more than a doubling of annual deployment to **2.5 GW per year** from 2030 to 2050.

Offshore wind power needs sufficient space, as the full load operating time may otherwise shrink from currently around 4,000 hours per year to between 3,000 and 3,300 hours.

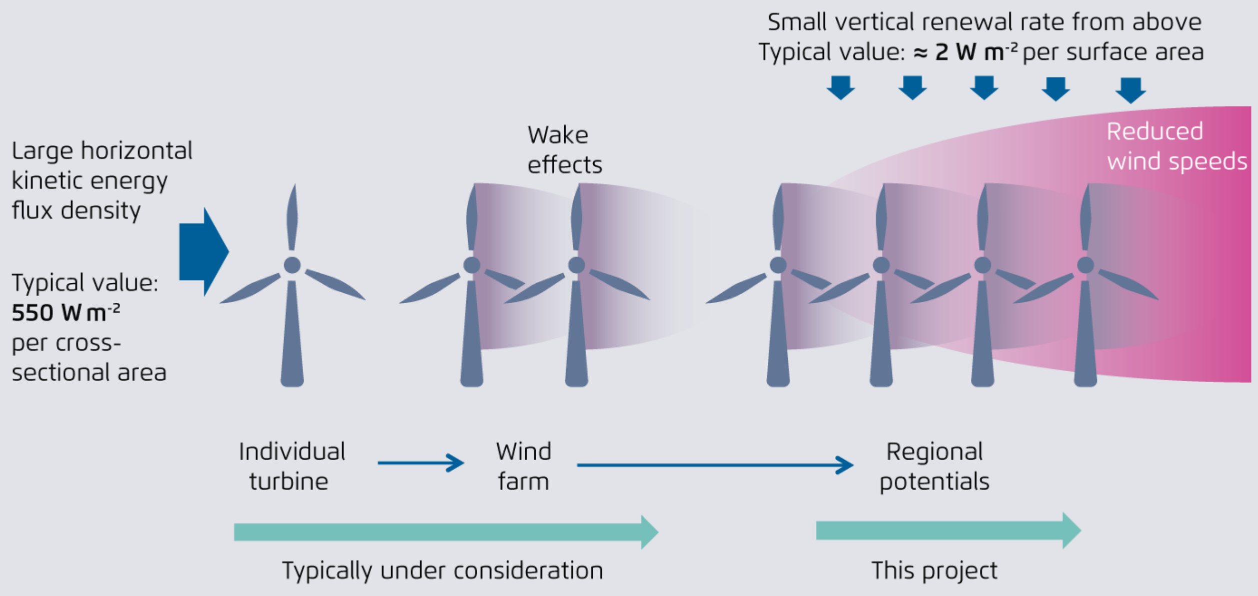
Full-load hours achievable depending on area for offshore wind deployment in the North Sea (and expected yield in TWh)



Agora Energiewende & Agora Verkehrswende (2020)

The more turbines are installed in a region, the less efficient offshore wind production becomes due to a lack of wind recovery.

The yields of many wind turbines decline by different factors



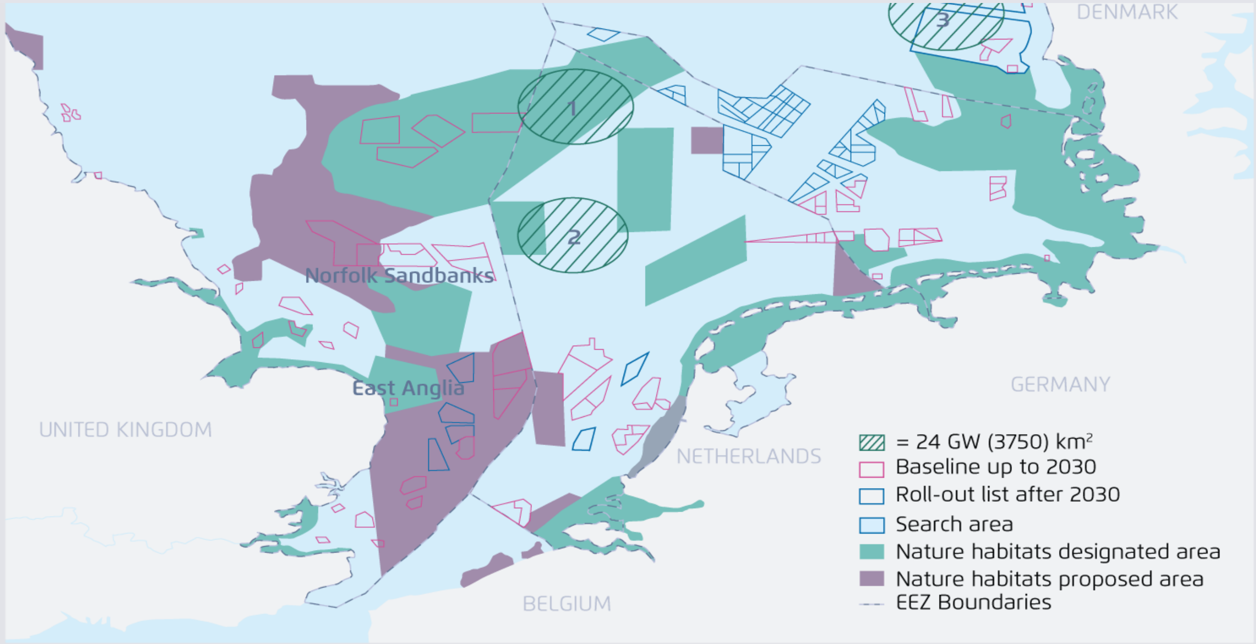
Note: Based on typical values for the annual means for the North Sea. Actual values show large variations due to varying wind conditions.

Agora Energiewende & Agora Verkehrswende (2020)

- The more the surrounding horizontal air flow is affected, the greater the reduction in downstream wind speeds, because additional kinetic energy can effectively only come from higher atmospheric layers, and the **vertical renewal rate from above is limited.**
- If Germany were to install 50 to 70 GW solely in the German Bight, the number of **full-load hours** achieved by offshore wind farms would **decrease considerably**.

Countries on the North and Baltic Seas should cooperate with a view to maximizing the wind yield and full-load hours of their offshore wind farms.

Illustrative areas for the development of o shore wind hubs in the North Sea



Note: Those locations do not represent preferences for the location of an initial project. Rather, they have been used to test location-specific impacts on hub-and-spoke design.

Agora Energiewende & Agora Verkehrswende (2020), adapted

- → The planning and development of wind farms – as well as **broader maritime spatial planning** – should be intelligently coordinated across national borders.
- → Sufficiently large spaces between wind farms should be preserved in order to **ensure replenishment of wind speeds**.
- → Replenishment areas could potentially be reserved for other purposes, i.e. shipping corridors or nature conservation.
- → **Cross-border effects** of wind depletion should be scrutinized
- → **Floating offshore** wind farms could enable the creative integration of deep waters into wind farm planning.

Key conclusions

1	**Offshore wind energy, which has an installed capacity potential of up to 1,000 GW, is a key pillar of the European energy transition.**
2	**Scenarios projecting near climate neutrality by 2050 assume an installed capacity of 50 to 70 GW of offshore wind in Germany, generating some 200 to 280 TWh of electricity per year.**
3	**Offshore wind power needs sufficient space, as the full load operating time may otherwise shrink from currently around 4,000 hours per year to between 3,000 and 3,300 hours.**
4	**Countries on the North and Baltic Seas should cooperate with a view to maximizing the wind yield and full-load hours of their offshore wind farms.**

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Agora Energiewende is a joint initiative of the Mercator Foundation and the European Climate Foundation.

Further publications by Agora Energiewende

EU-wide innovation support is key to the success of electroly-sis manufacturing in Europe	Building sector Efficiency: A crucial Component of the Energy Transition	European Energy Transition 2030: The Big Picture	The Future Cost of Electricity-Based Synthetic Fuels	Heat Transition 2030
				
> full study	> full study (EN)	> full study	> full study > PtG/PtL calculator	> summary (EN) > full study (DE)
	> slide deck (DE)	> slide deck	> slide deck > webinar	> slide deck