Pre-feasibility Study on Potential for Offshore Wind in UKRAINE
Phase 1

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Agenda

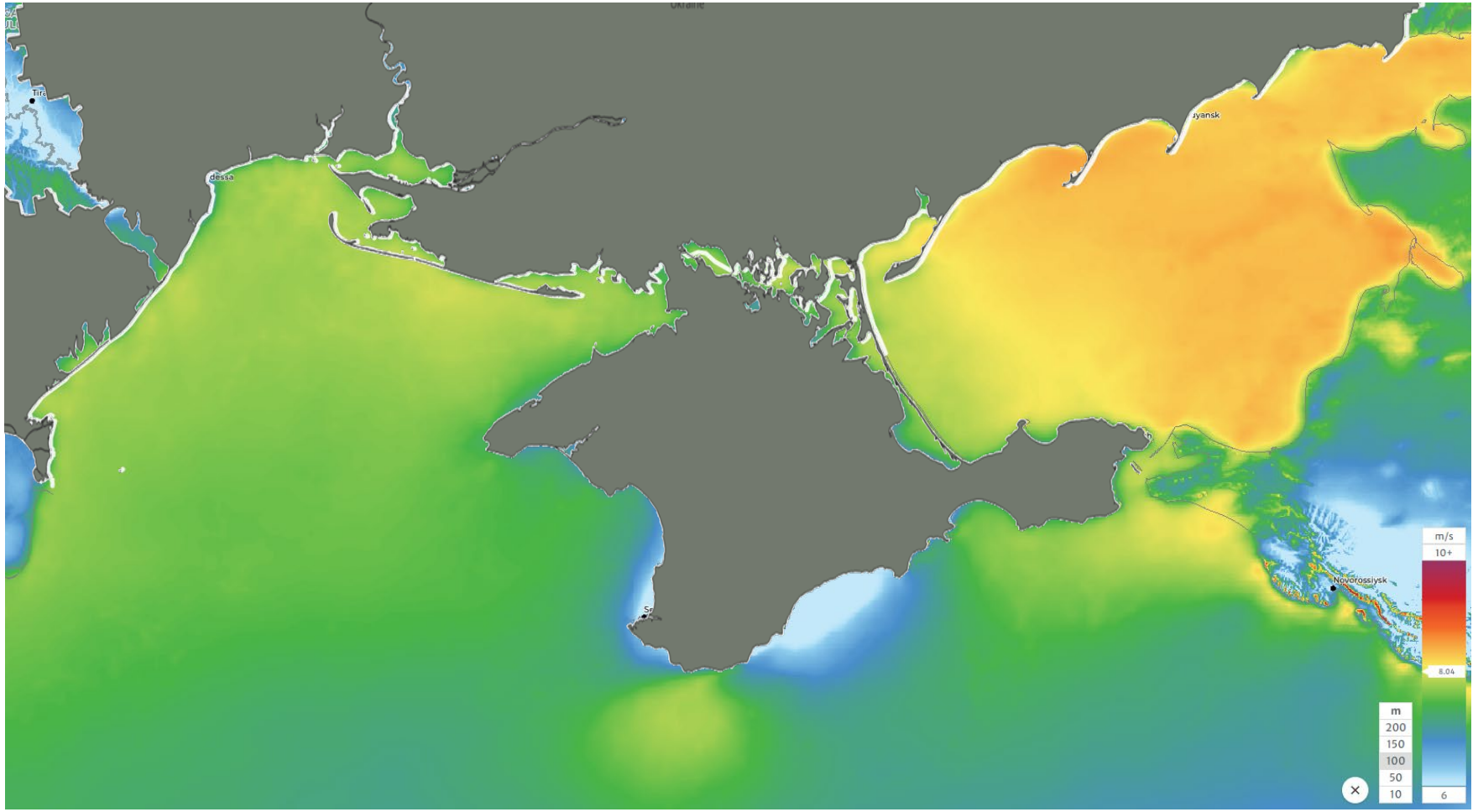
- Wind Climate Offshore Ukraine
- Geospatial Assessment
- Energy Yield Assessment – three hypothetical wind farms
- Levelized Cost Of Energy Estimates
- Scale-up Strategies
- Summary

Analysis of Wind Potential

Mean Wind Speed at 100m

https://globalwindatlas.info/en

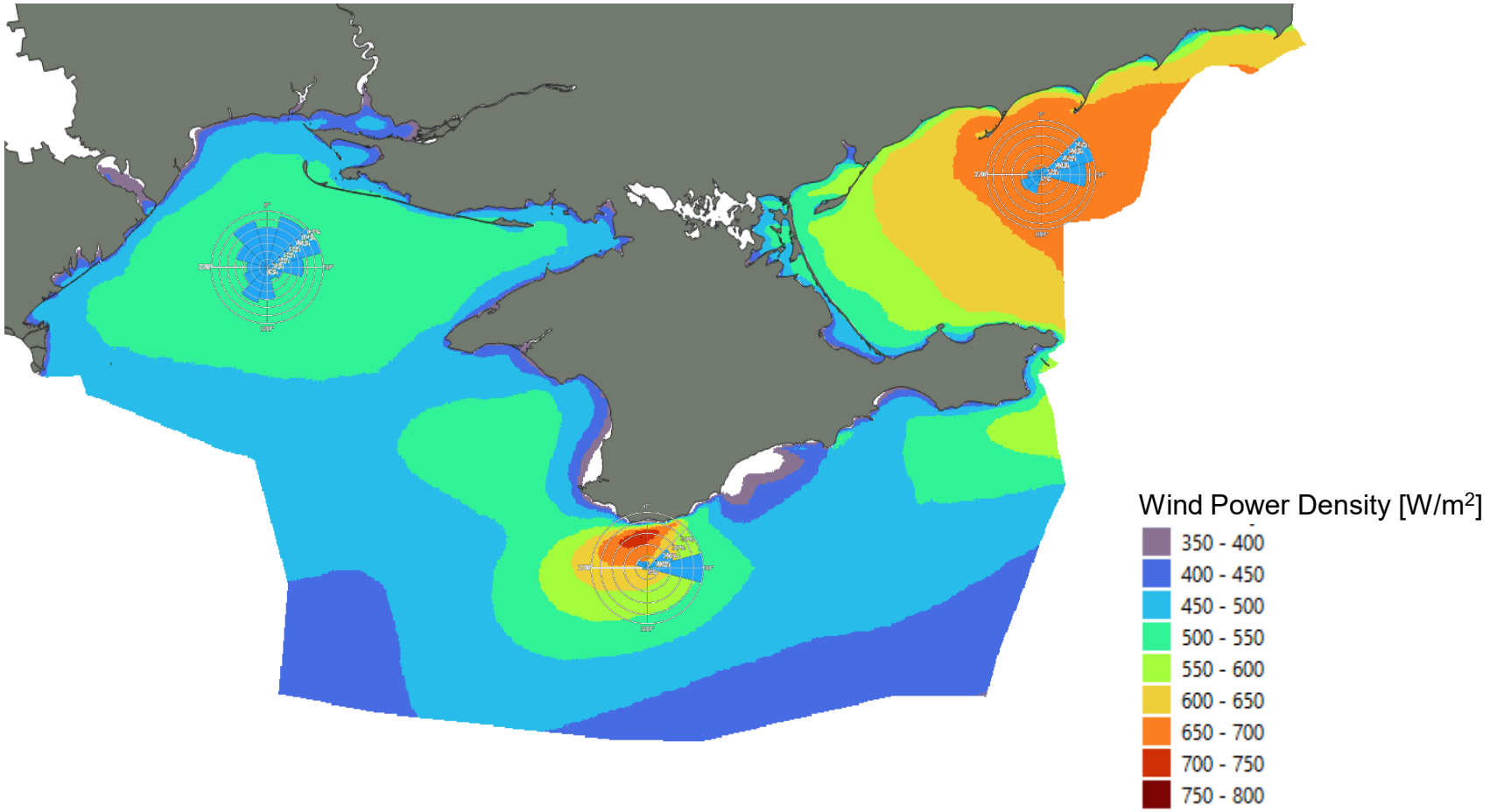
Wind data from
Global Wind Atlas



Mean Wind Power Density and Wind Power Rose at 100 m

https://globalwindatlas.info/en

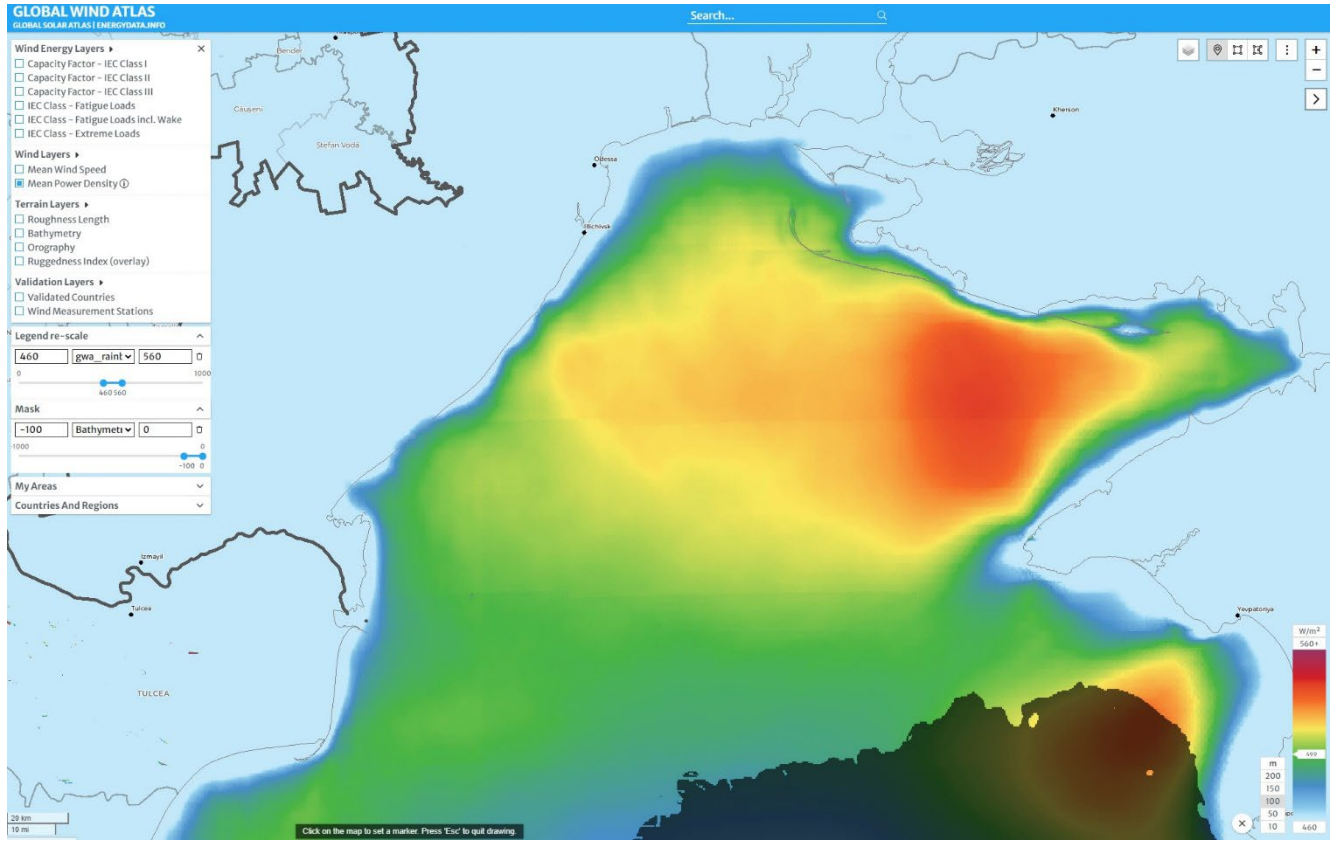
Wind data from
Global Wind Atlas



Mean Wind Power Density at 100 m

Wind data from
Global Wind Atlas

https://globalwindatlas.info/en



Mean Wind speed from

Vortex maps in the Everoze report

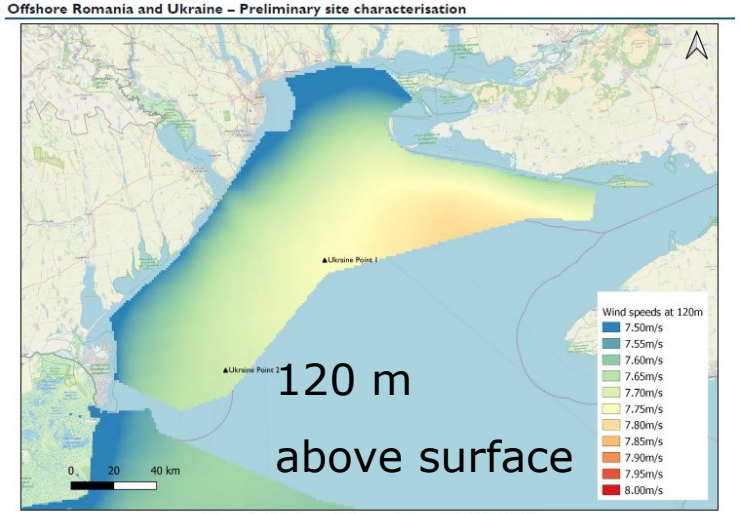


Figure 4: Ukraine wind speed map at 120.0m MSL

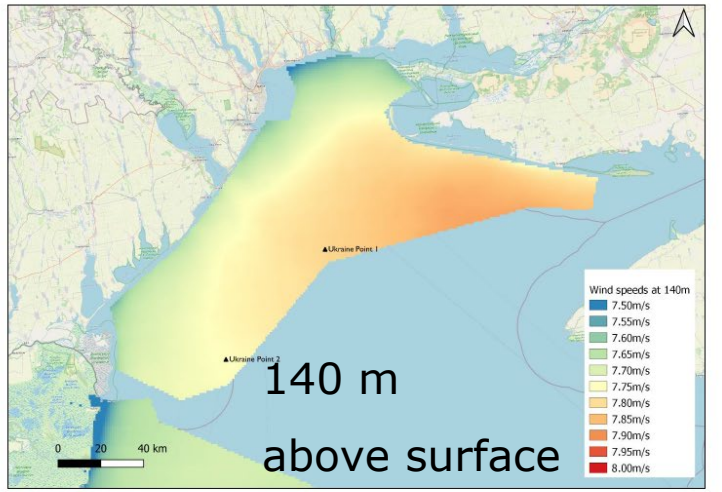


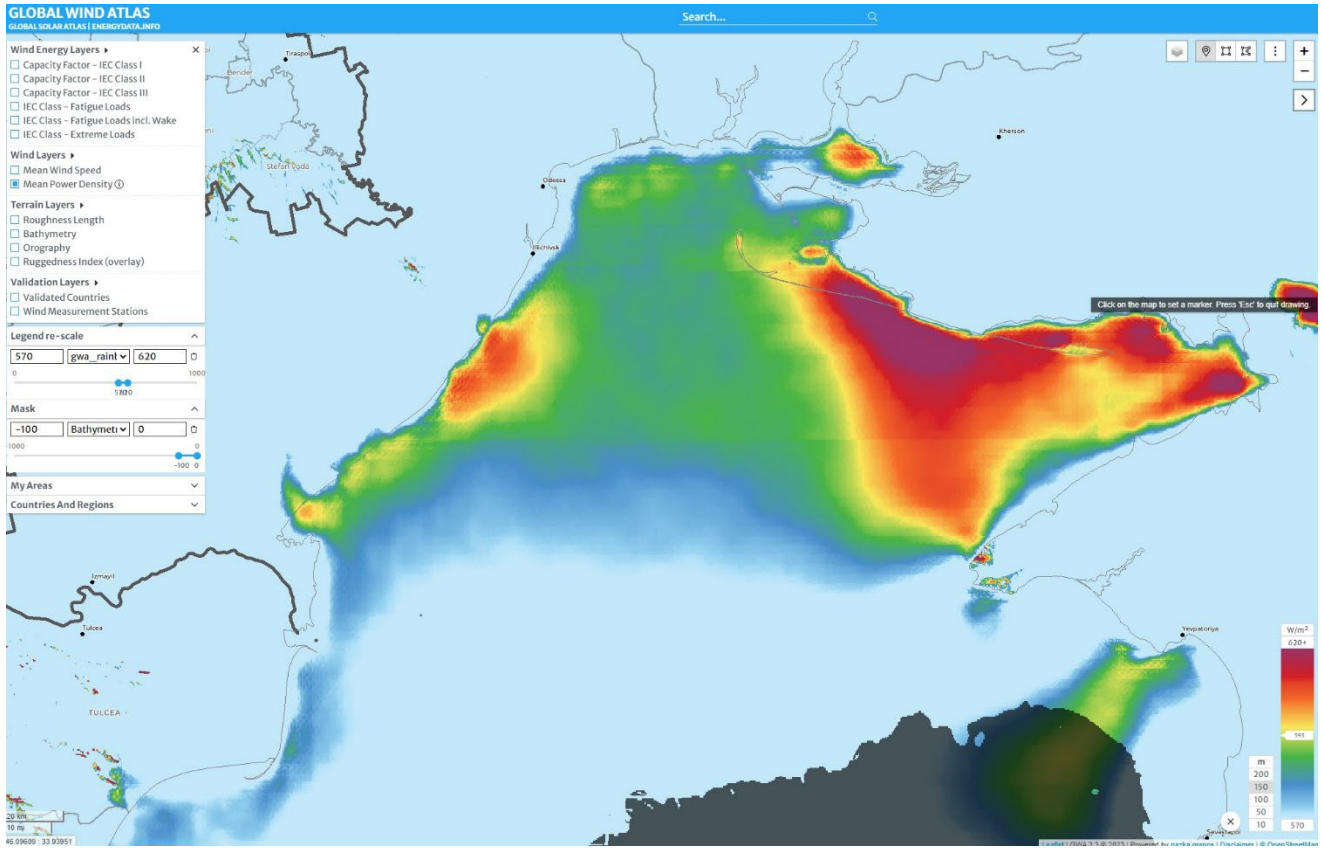
Figure 5: Ukraine wind speed map at 140.0m MSL

everoze

Mean Wind Power Density at 150 m

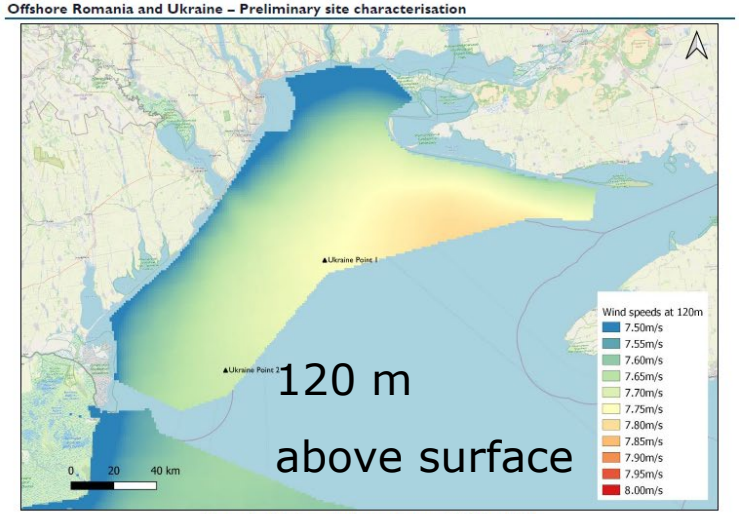
Wind data from
Global Wind Atlas

https://globalwindatlas.info/en



Wind speed from

Vortex map in the Everoze report



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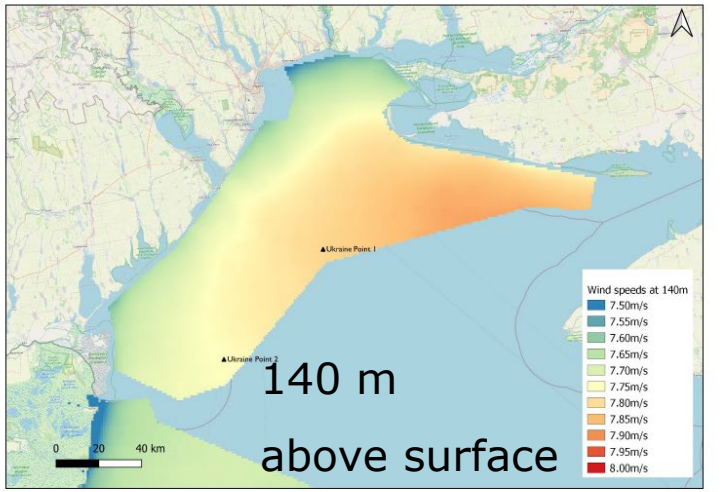
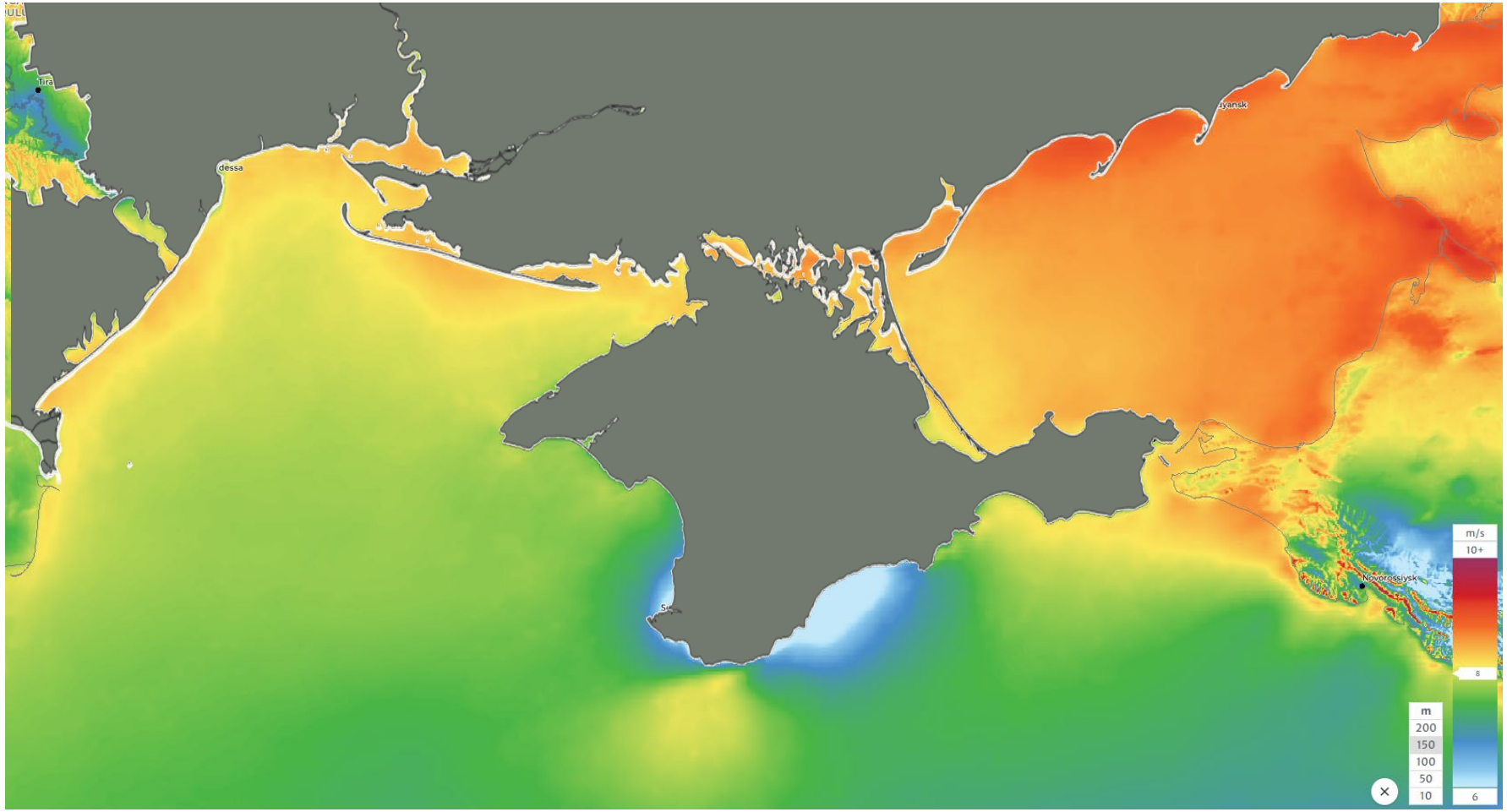


Figure 5: Ukraine wind speed map at 140.0m MSL

Mean Wind Speed at 150m

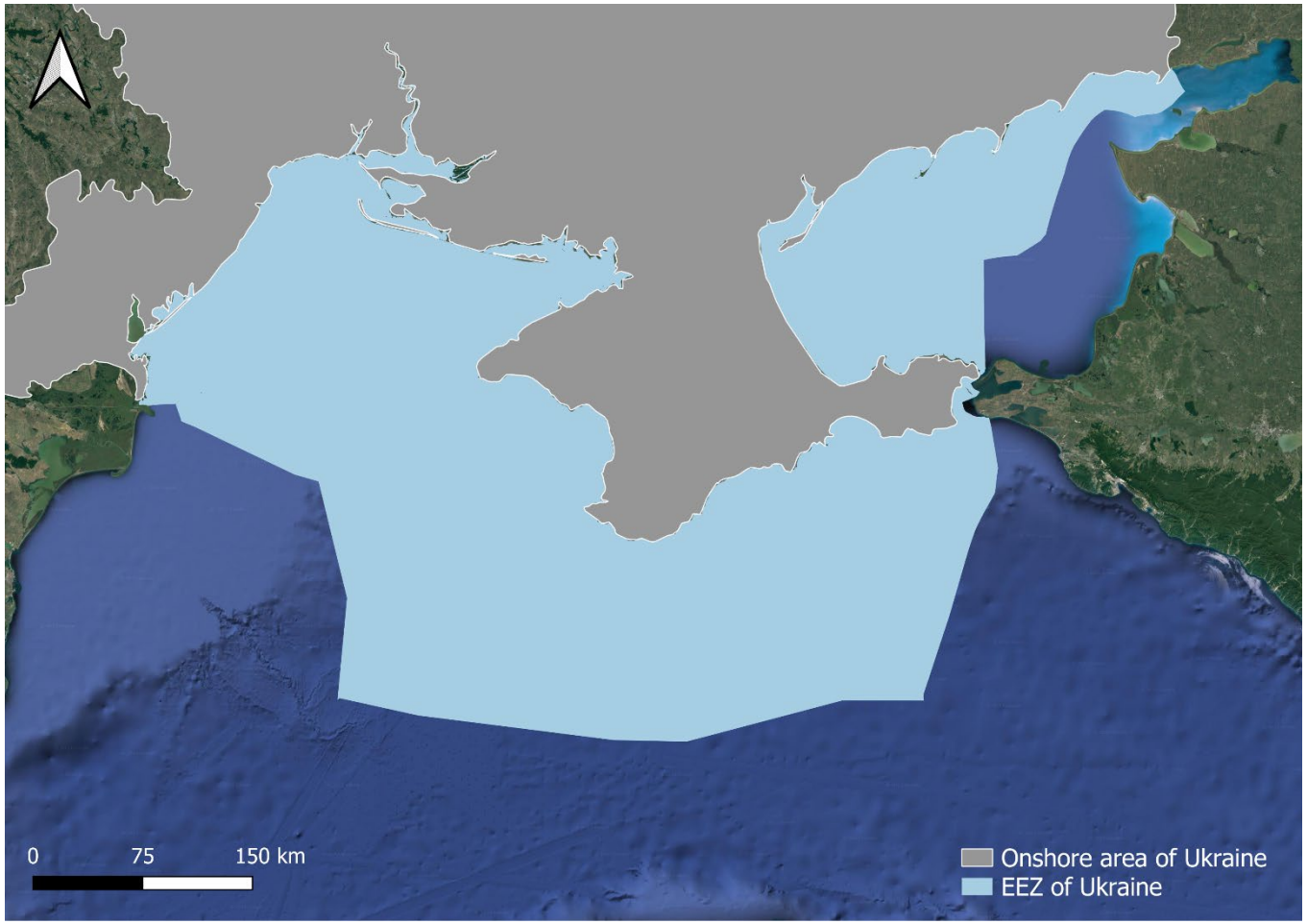
https://globalwindatlas.info/en

Wind data from
Global Wind Atlas



Geospatial Assessment

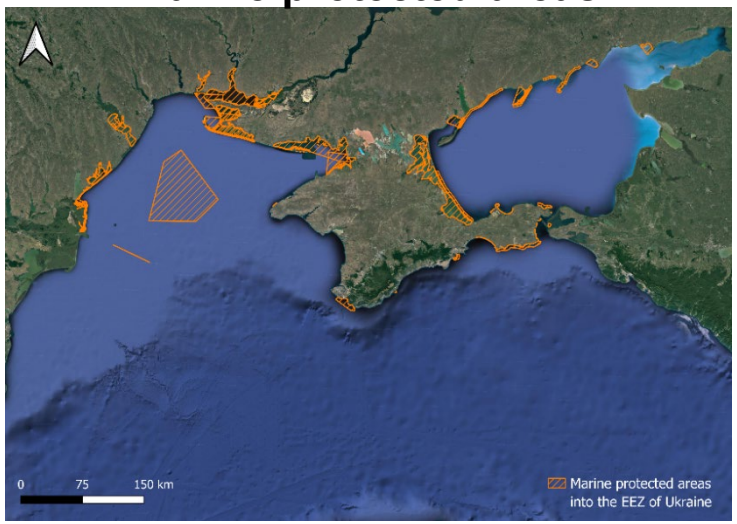
Exclusive Economic Zone (EEZ) and Onshore area of Ukraine



Source: World Bank Official Boundaries, https://datacatalog.worldbank.org/search/dataset/0038272/World-Bank-Official-Boundaries
MarineRegions.org., https://www.marineregions.org/

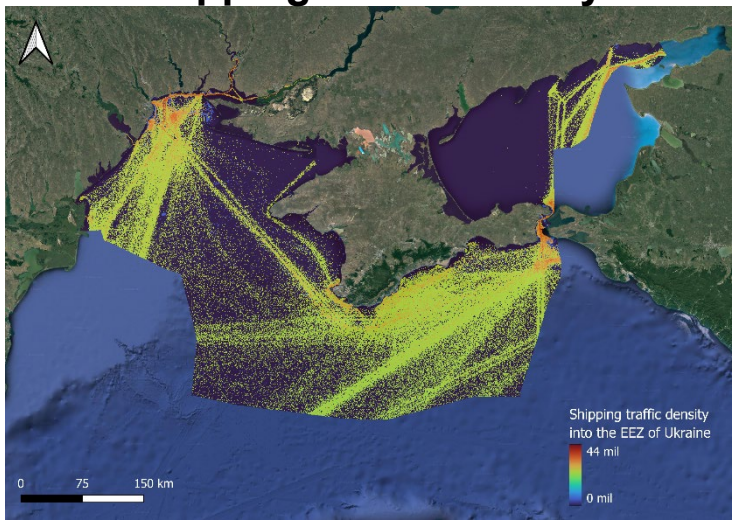
Main constraints for geospatial assessment

Marine protected areas



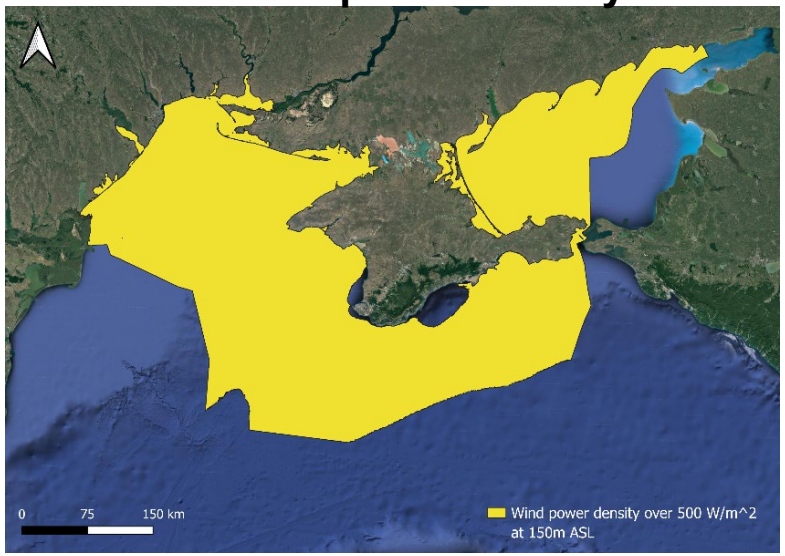
Source: Protected Planet, https://www.protectedplanet.net/en

Shipping traffic density



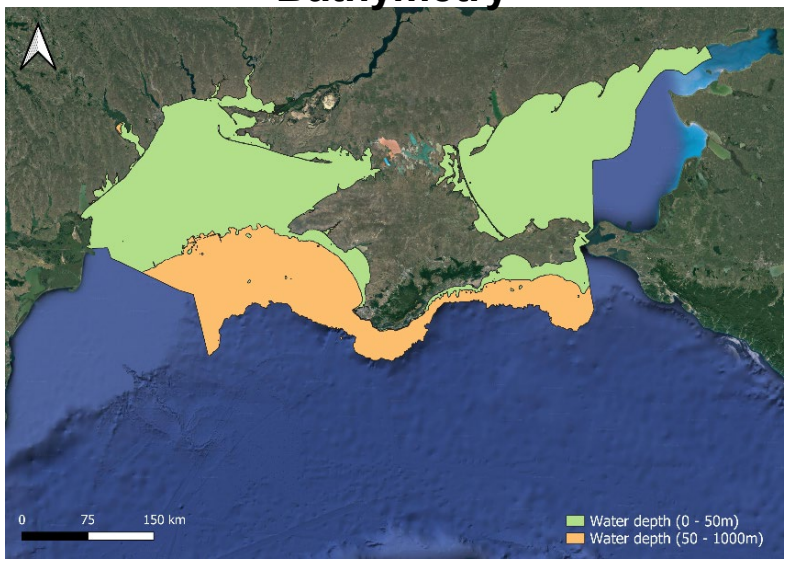
Source: The World Bank – Data Catalog (2015-2021), https://datacatalog.worldbank.org/search/dataset/0037580/Global-Shipping-Traffic-Density

Mean wind power density



Source: Global Wind Atlas, https://globalwindatlas.info/en

Bathymetry



Source: Global Wind Atlas, https://globalwindatlas.info/en

Site selection – Criteria and restrictions for Bottom-fixed and Floating Wind Turbine areas

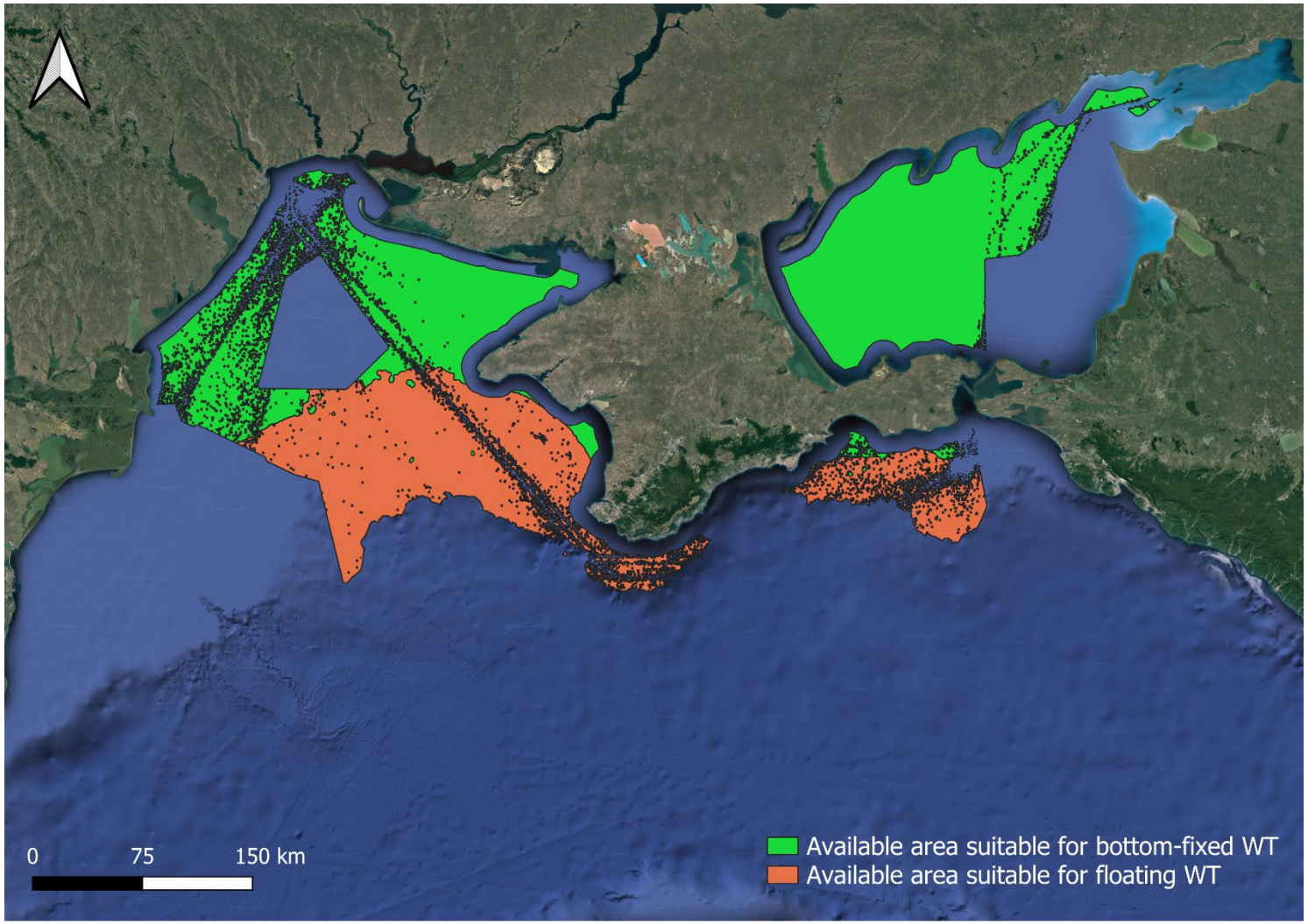
Bottom-fixed WT areas

- Coastal line of Ukraine plus a buffer zone of 10km
- Marine protected areas plus a buffer zone of 2km
- Wind power density @ 150m ≥ 500 W/m^2
- Water depth ≤ 50m
- High shipping traffic density ≥ 30mil plus a buffer zone of 250m
- Available area = **29699 km^2**

Floating WT areas

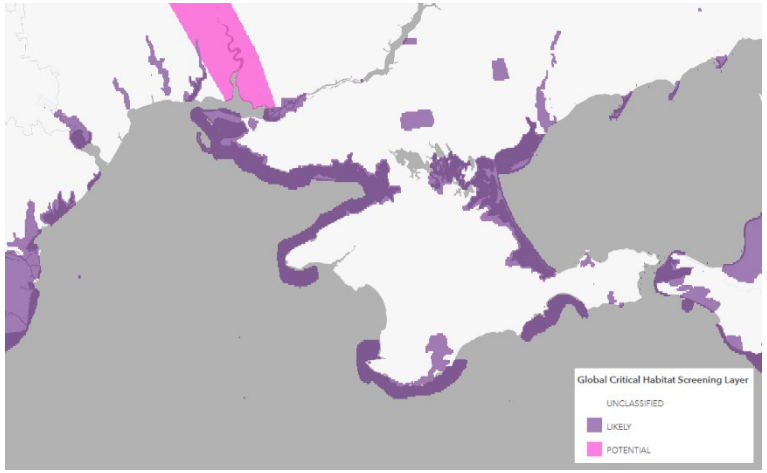
- Coastal line of Ukraine plus a buffer zone of 10km
- Marine protected areas plus a buffer zone of 2km
- Wind power density @ 150m ≥ 500 W/m^2
- 50m < Water depth ≤1000 m
- High shipping traffic density ≥ 30mil plus a buffer zone of 250m
- Available area = **19439 km^2**

Suitable areas for bottom-fixed and floating wind turbines



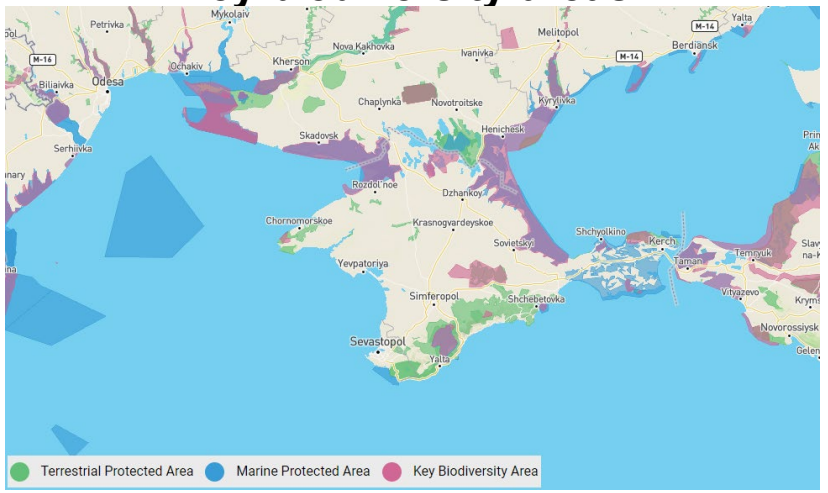
Checks against other datasets of sensitive areas

Global critical habitats



Source: UNEP-WCMC, https://data.unep-wcmc.org/datasets/44

Key biodiversity areas

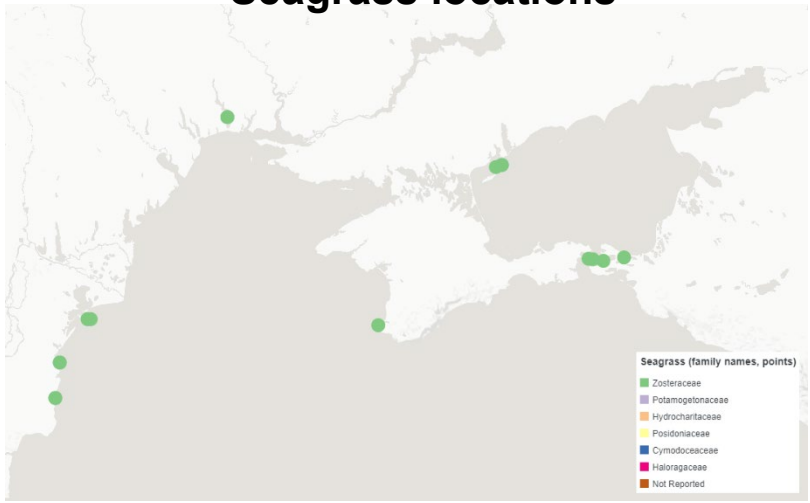


Source: IBAT Country Profile, https://www.ibat-alliance.org/country_profiles/UKR

Ramsar wetlands

Source: Ramsar Sites Information Service (RSIS), https://resourcewatch.org/

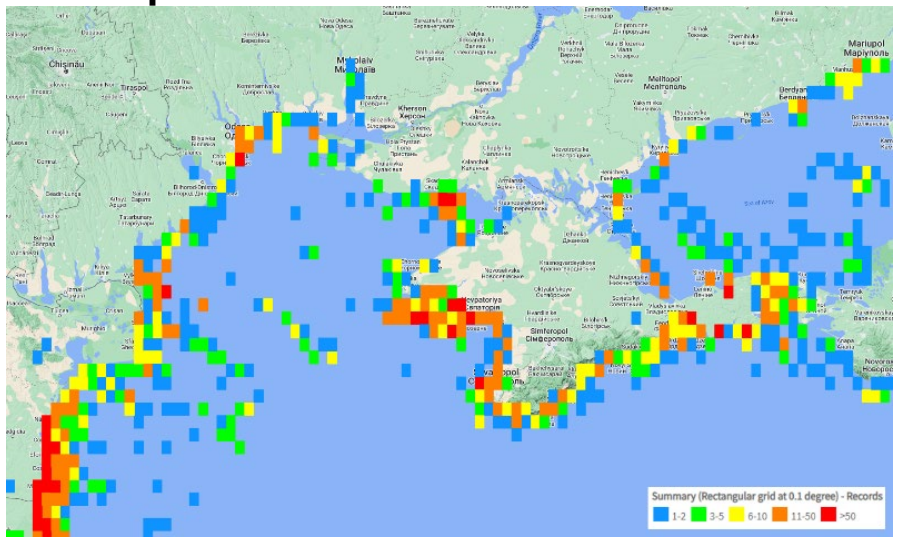
Seagrass locations



Source: UNEP-WCMC & Short FT, https://resourcewatch.org/

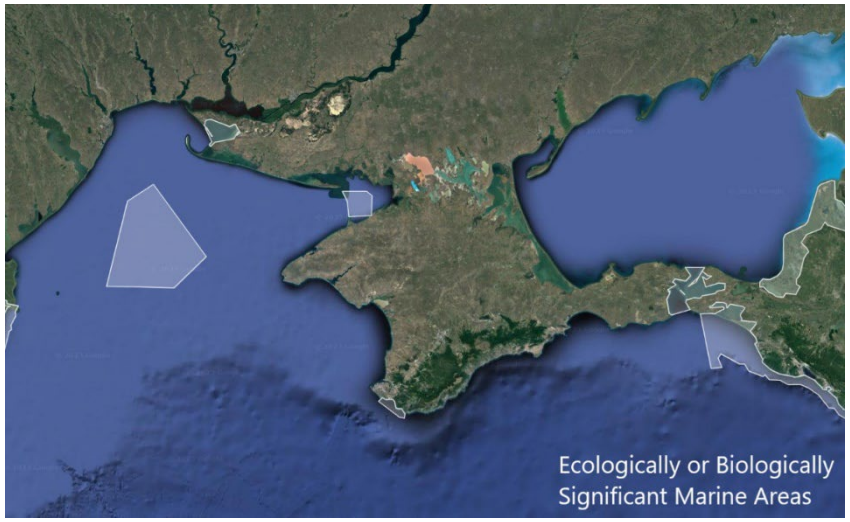
Checks against other datasets

Grid representation of marine mammals as records



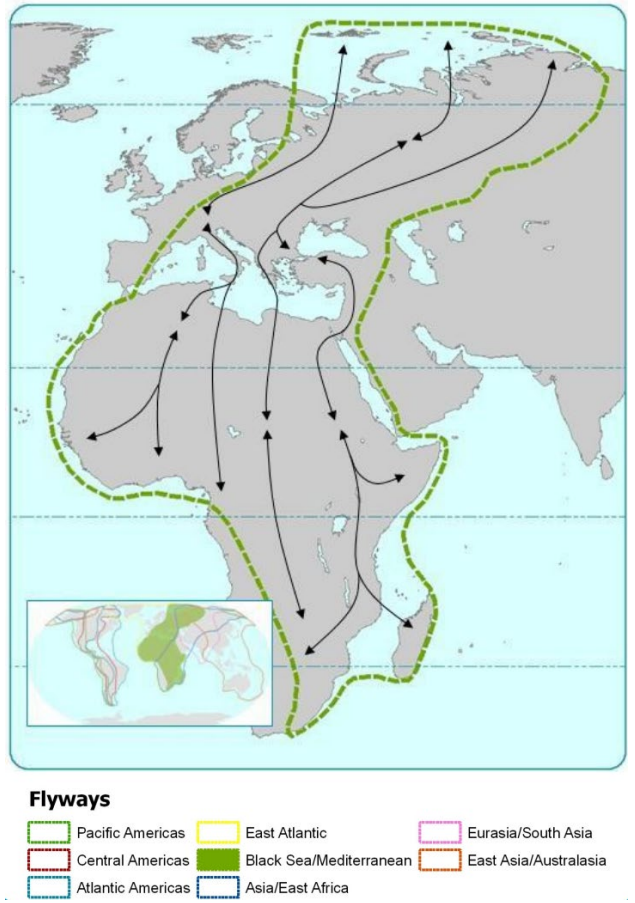
Source: OBIS-SEAMAP, https://seamap.env.duke.edu/species/179913

Ecologically of Biologically Significant Marine Areas



Source: EBSA, https://www.cbd.int/ebsa/

Bird Flyways



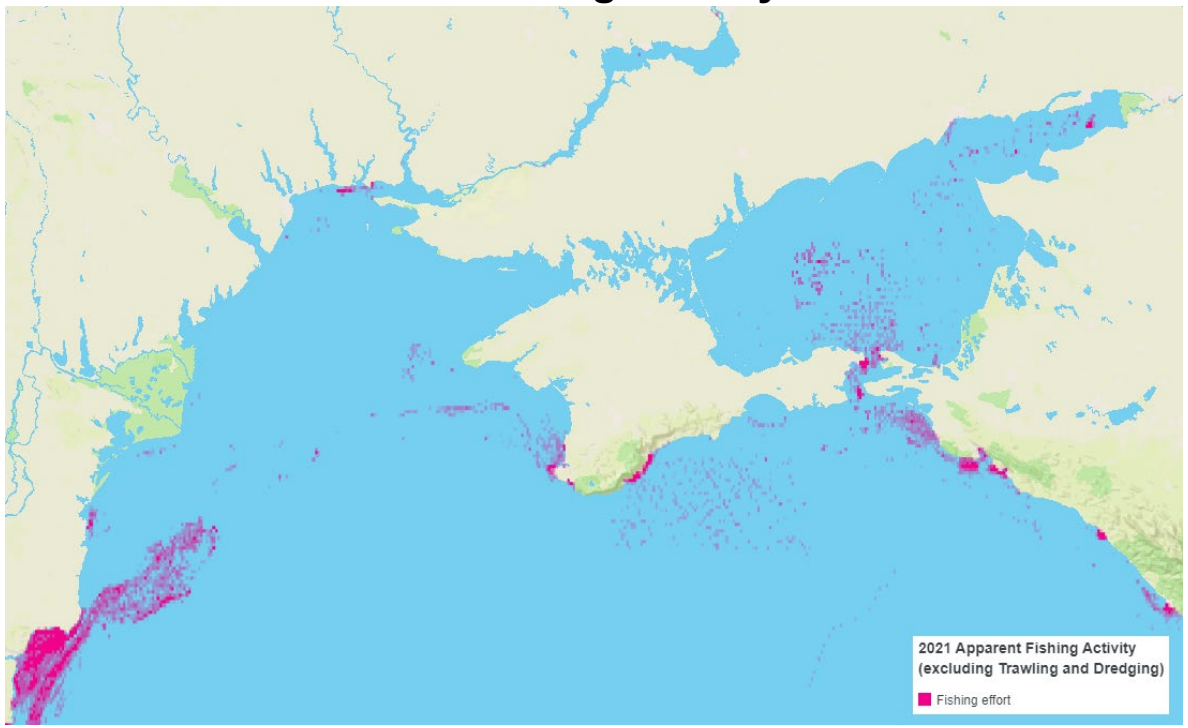
Source: BirdLife, http://datazone.birdlife.org/userfiles/file/sowb/flyways/5_Mediterranean_Black_Sea_Factsheet.pdf

Checks against other datasets

Ports and Airports

Source: National Geospatial Intelligence Agency, World Port Index, https://resourcewatch.org/
OpenFlights, Airports, https://resourcewatch.org/

Fishing Activity



Source: Global Fishing Watch, https://resourcewatch.org/

Energy Yield Assessment

Wind Turbine

- Turbine specifications
  8.25 MW capacity
  140 m hub height
  164 m rotor diameter

  4.0 m/s cut-in wind speed
  13.0 m/s rated wind speed

Wind turbine power and thrust curves

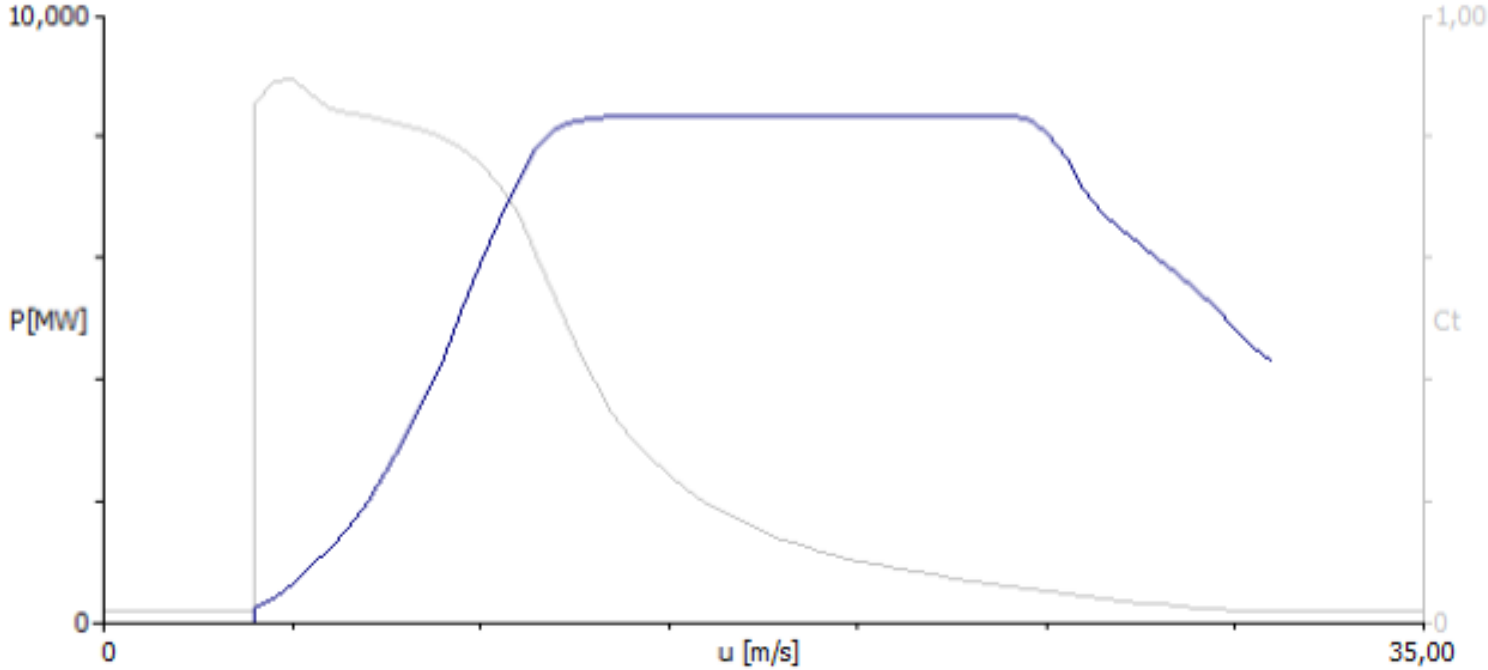


Figure 21: *Power and thrust coefficient curves for the generic 8.25 MW wind turbine.*

Site Locations

3 sites

Site 1
Northern Black Sea
Bottom-fixed

Site 2
Sea of Azov
Bottom-fixed

Site 3
West of Crimea
Floating

Table 2: Main characteristics of the wind farm sites

Characteristic	Site 1	Site 2	Site 3
Average water depth	25 m	8 m	55 m
Distance to shore	15.3 km	13.7 km	45.9 m
Distance to port	124 km (Odessa)	112 km (Mariupol)	161 km (Odessa)
Mean wind power density	602 W/m²	755 W/m²	549 W/m²

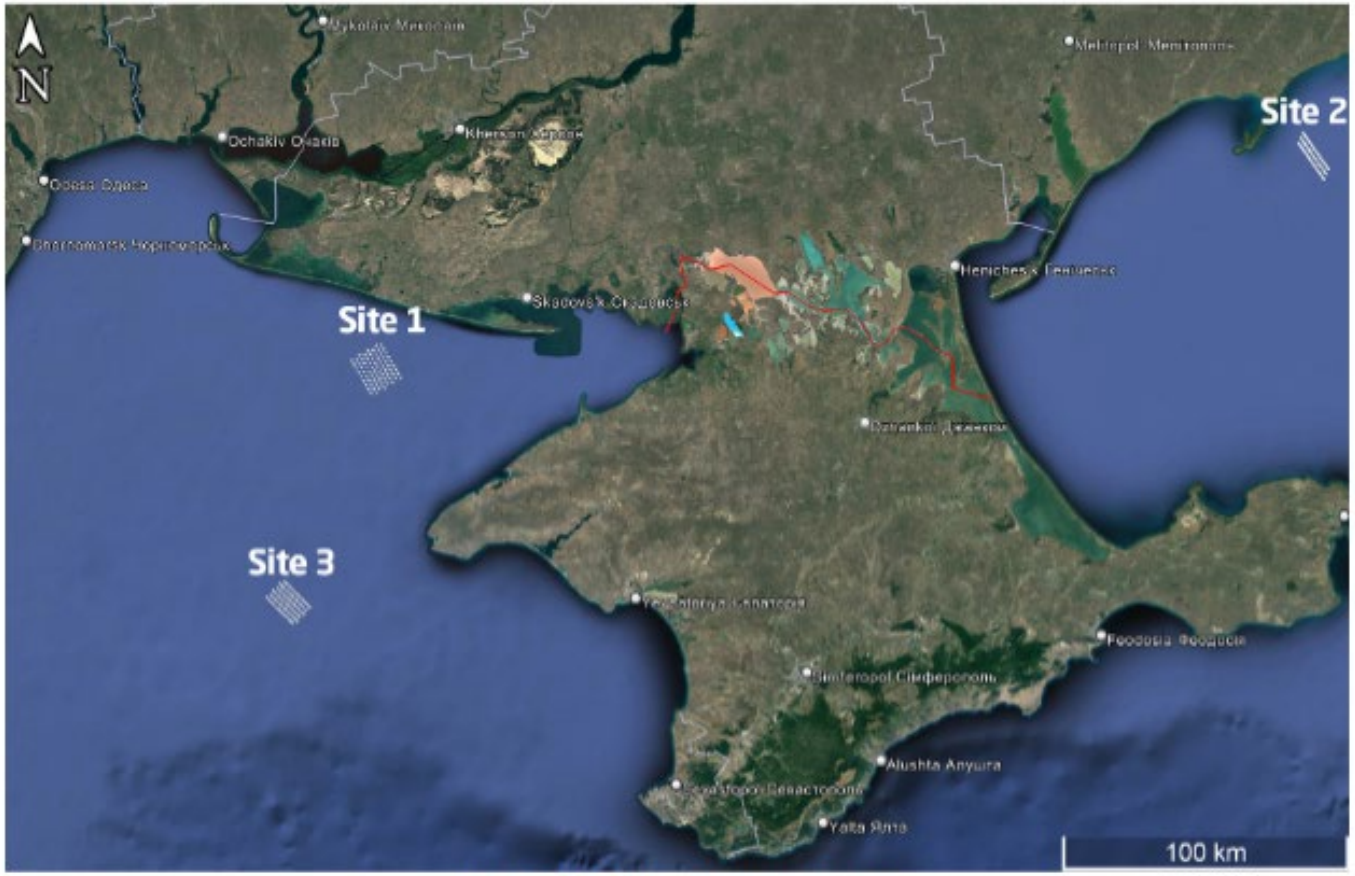


Figure 22: *Site locations in Ukraine*

Layouts

594 MW (**~600 MW**)

Wind direction distribution used to determine windfarm layouts:

- Turbine spacing
- Windfarm dimensions and shape
- Windfarm orientation

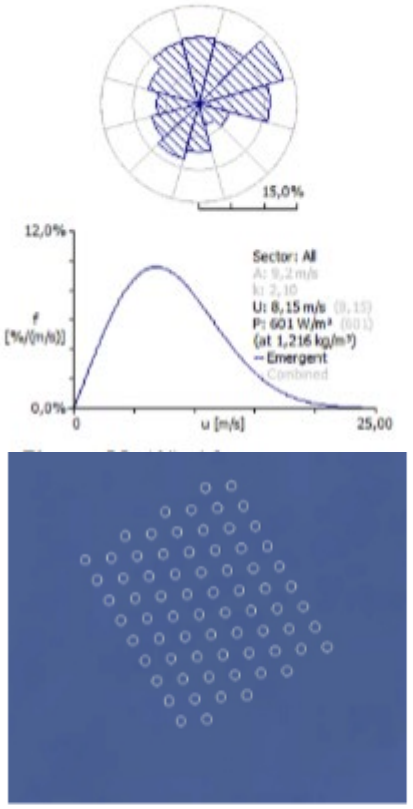


Figure 23: *Site 1 wind farm layout*

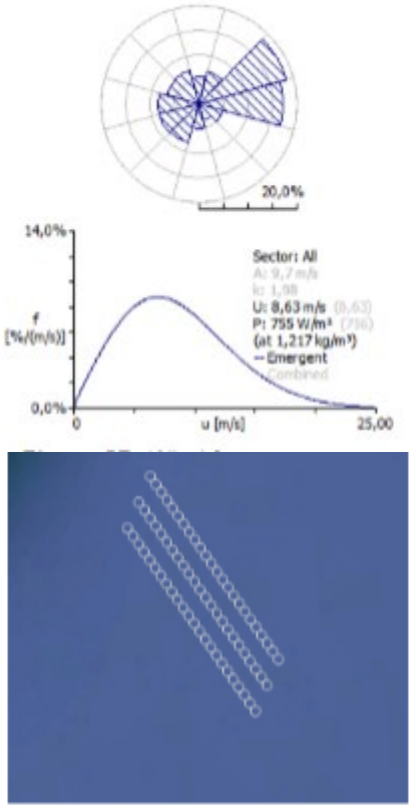


Figure 24: *Site 2 wind farm layout*

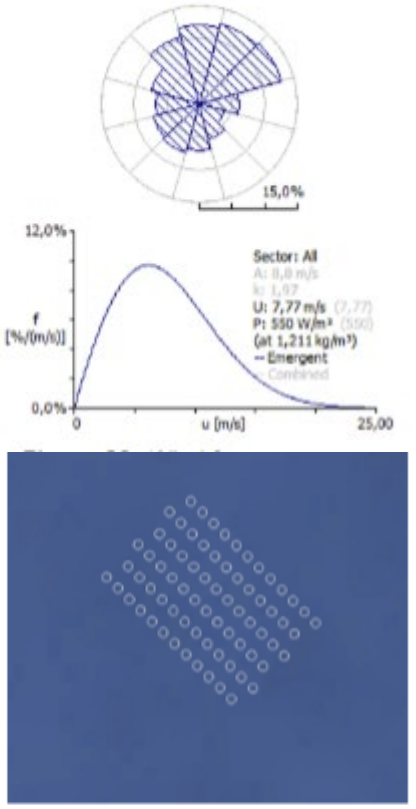


Figure 25: *Site 3 wind farm layout*

Table 3: Layout characteristics of the wind farm sites

Characteristic	Site 1	Site 2	Site 3
Location	Northern Black Sea	Sea of Azov	Black Sea - West of Crimea
Number of rows	8	3	6
Turbines per row	9	24	12
Turbine spacing	10D	4D	7D
Row spacing	10D	10D	10D

WAsP https://www.wasp.dk

Global Wind Atlas – Methodology https://globalwindatlas.info/en

Annual Energy Production

3 sites

Site 1
Northern Black Sea
Lowest wake losses of the 3 sites

Site 2
Sea of Azov
Highest production of the 3 sites

Site 3
West of Crimea
Lowest production of the 3 sites

Parameter	Site 1	Site 2	Site 3
Mean wind speed	8.1 m/s	8.6 m/s	7.8 m/s
Wake loss	6.88%	8.69%	9.41%
Potential AEP	2106.6 GWh	2223.8 GWh	1892.1 GWh
Total losses	17.8%	20.1%	21.0%
Net AEP	1921.2 GWh	2028.1 GWh	1725.6 GWh
CF	36.9%	39.0%	33.2%

Levelized Cost of Energy (LCOE) Estimates

Levelized Cost of Energy (LCOE) Estimates

The LCOE is the minimum price at which energy produced must be sold for the duration of the project's operating phase to break even.

The unit is **EUR per MWh** of net production.

The LCOE can be calculated by dividing the net present value of lifetime costs by lifetime energy produced.

Assumptions and inputs:

- Seven-year development and 25 operation:
  - ❖Development phase (five years): 2024 – 2028
  - ❖Financial investment decision (FID): 2029
  - ❖Construction (two years): 2029-2030
  - ❖Operation (25 years): 2031-2055

Levelized Cost of Energy (LCOE) Estimates Inputs and Assumptions

- Costs per MW offshore wind CAPEX and OPEX data from Bloomberg New Energy Finance (BNEF)
- Assume DEVEX is equal to 3% of total CAPEX
- Immature market premium: estimate from two scenarios. Scenario 1 = 5%. Scenario 2 = 20%
- Assume the same OPEX range for floating and bottom-fixed technologies

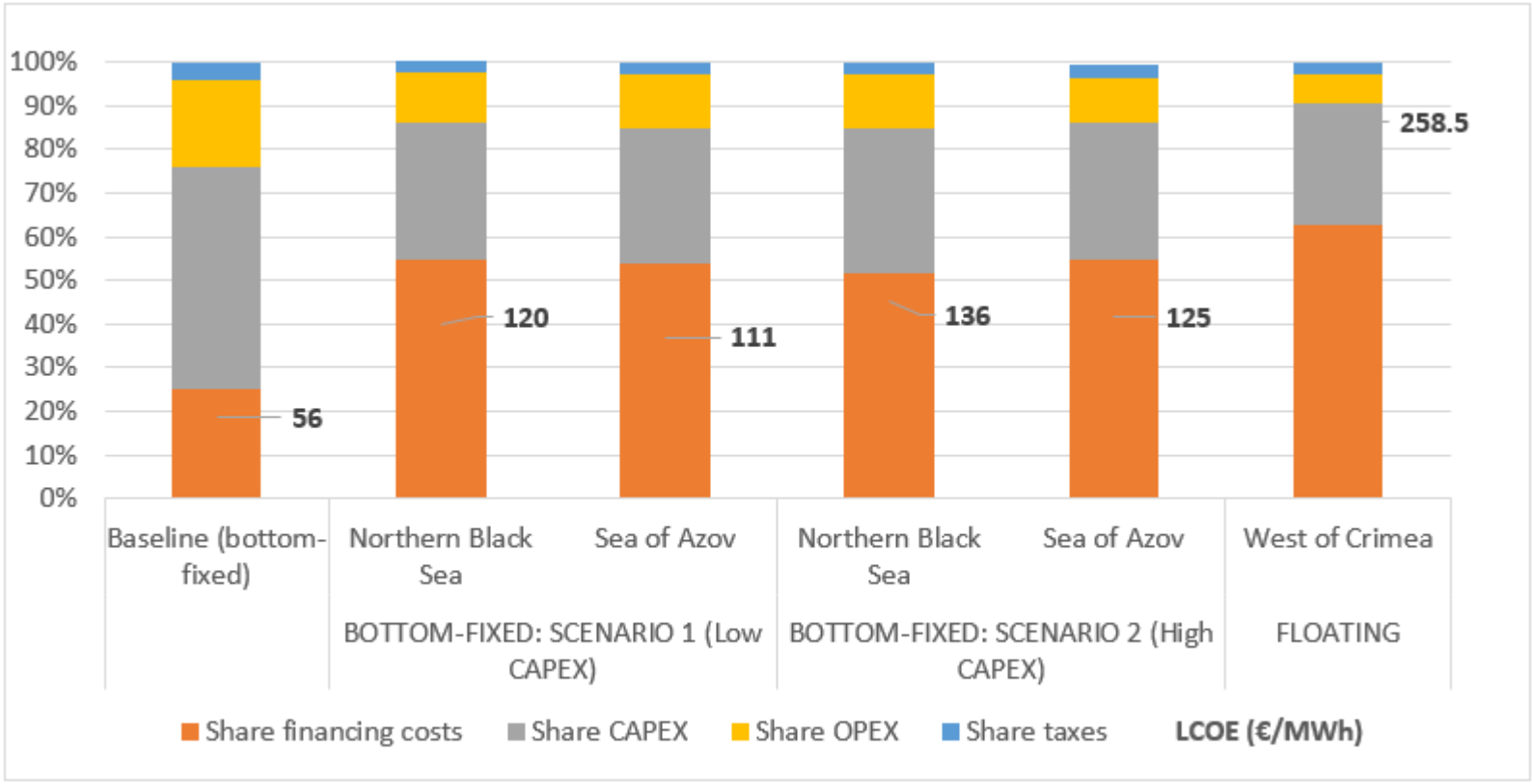
- Weighted Average Cost of Capital (WACC) (not adjusted for inflation) of 14% - 16% for renewable energy from BNEF
- Assume a 5% rate of inflation: real WACC of 8.6% to 10.5% (bottom-fixed), real WACC of 10.6% - 12.5% (floating)
- Baseline project assumption : a real WACC of 2.5% - 3.2% (with an inflation rate of 2%)
- Assume corporate tax rate of 18% and a depreciation term of (minimum) five years
- Baseline assumption: 25% corporate tax rate and 15-year depreciation term (~7% of project cost per year)

[1] J. Badger, B.O. Hansen, A. Mitsakou, S.S. Blagojevic, T. Hansen, N.-E. Clausen, Case Study-based Prefeasibility Assessment of Offshore
[2] Wind Resources in Egypt, DTU Wind and Energy Systems, Roskilde, 2022. https://orbit.dtu.dk/en/publications/case-study-based-prefeasibility-assessment-of-offshore-wind-resou.
[3] G. Trypolska, O. Riabchyn, Experience and Prospects of Financing Renewable Energy Projects in Ukraine, IJEEP. 12 (2022) 134–143.
[4] T. Kurbatova, I. Sotnyk, O. Prokopenko, I. Bashynska, U. Pysmenna, Improving the Feed-in Tariff Policy for Renewable Energy Promotion in Ukraine's Households, Energies. 16 (2023) 6773.
[5] M. Trifonova, M. Vladimirov, Wind Power Generation in Bulgaria, Center for the Study of Democracy, 2021.

Levelized Cost of Energy (LCOE) Estimates

Project	LCOE [€/MWh]	Share Financing costs	Share CAPEX	Share OPEX	Share Taxes
Baseline (bottom-fixed)	48 – 64	11 – 18	25 – 32	11 – 12	2 – 3
BOTTOM-FIXED: SCENARIO 1 (Low CAPEX)					
Site 1 Northern Black Sea	98 – 142	50 – 82	34 – 41	12 – 15	3 – 4
Site 2 Sea of Azov	91 – 131	46 – 75	30 – 37	12 – 15	3 – 4
BOTTOM-FIXED: SCENARIO 2 (High CAPEX)					
Site 1 Northern Black Sea	111 – 161	57 – 72	37 – 47	14 – 15	4 – 5
Site 2 Sea of Azov	102 – 148	52 – 86	35 – 43	12 – 15	3 – 4
FLOATING					
Site 3 West of Crimea	223 – 294	124 – 192	67 – 77	16 – 17	7 – 8

Mean real LCOE values and mean shares of costs for offshore wind projects



Levelized Cost of Energy (LCOE) Estimates assuming baseline project WACC

LCOE in EUR/MWh

Project	Scenario 1 (low CAPEX)	Scenario 2 (high CAPEX)
Site 1 Northern Black Sea	61 – 81	68 – 91
Site 2 Sea of Azov	57 – 75	63 – 84
Site 3 West of Crimea	115 – 141	

Scaling Up

Maximum Installation Capacity

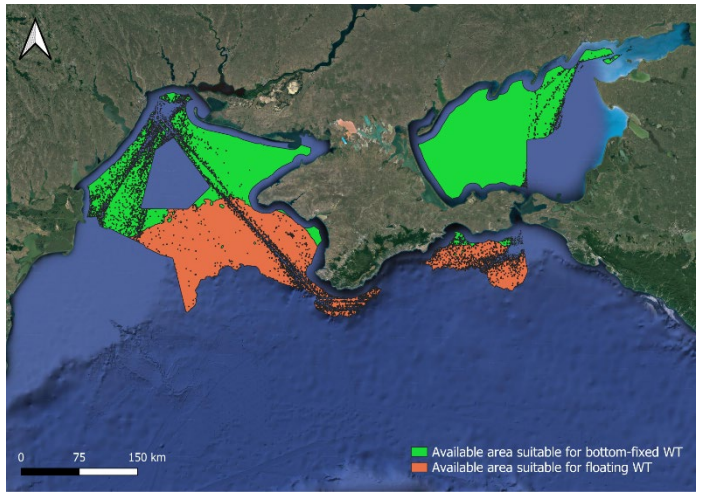
Assumptions

(calculated) Available area for Bottom-fixed wind turbines = 29,699 km^2

(estimated) Capacity Density , CD = 1 MW/km^2

Result

➔Total Capacity ~ 30 GW



Assumptions

(calculated) Available are for Floating wind turbines = 19,439 km^2

(estimated) Capacity Density , CD = 1 MW/km^2

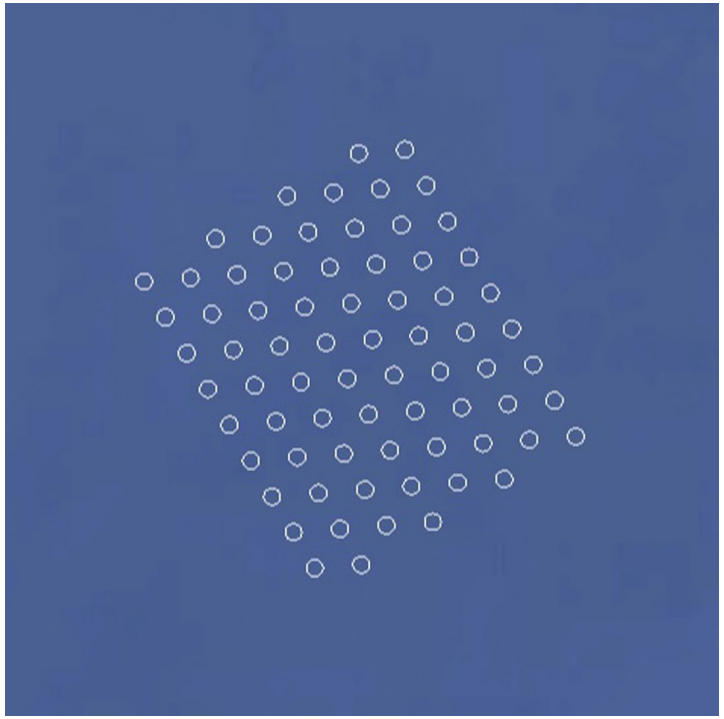
Result

➔Total Capacity ~ 20 GW

Hypothetical Wind Farm – Site 1

NET Capacity Factor = 36.9 %

Spacing : 10 D x 10 D
Area : 230 km^2
Total Capacity: 594 MW
Capacity Density = 2.6 MW/km^2
wake loss = 6.9 %



Hypothetical Wind Farm – Site 2

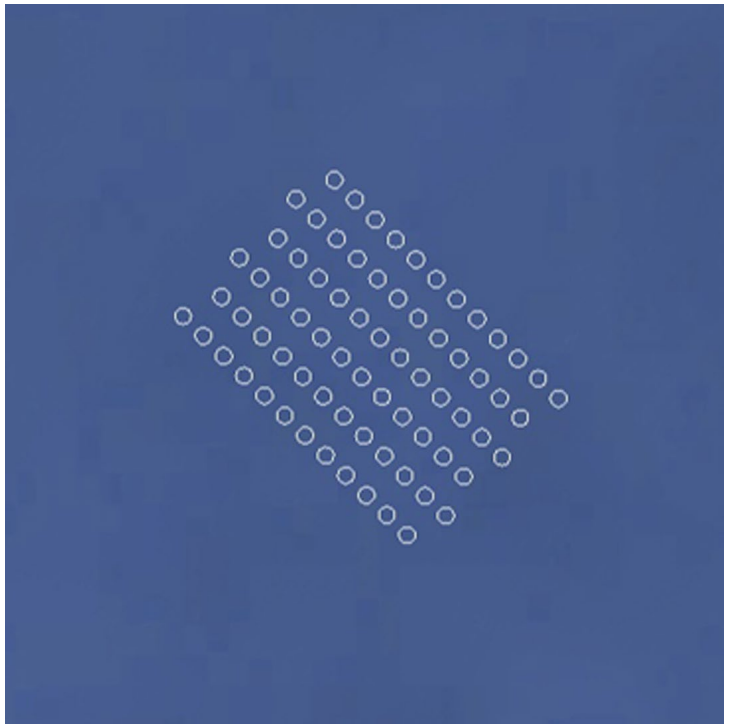
NET Capacity Factor = 39 %

Spacing : 4 D x 10 D
Area : 82 km^2
Total Capacity: 594 MW
Capacity Density = 7.2 MW/km^2
wake loss = 8.7 %

Hypothetical Wind Farm – Site 3

NET Capacity Factor = 33.2 %

Spacing : 7 D x 10 D
Area : 160 km^2
Total Capacity: 594 MW
Capacity Density = 3.7 MW/km^2
wake loss = 9.4 %



Wind farm size and wake effects

Recap:

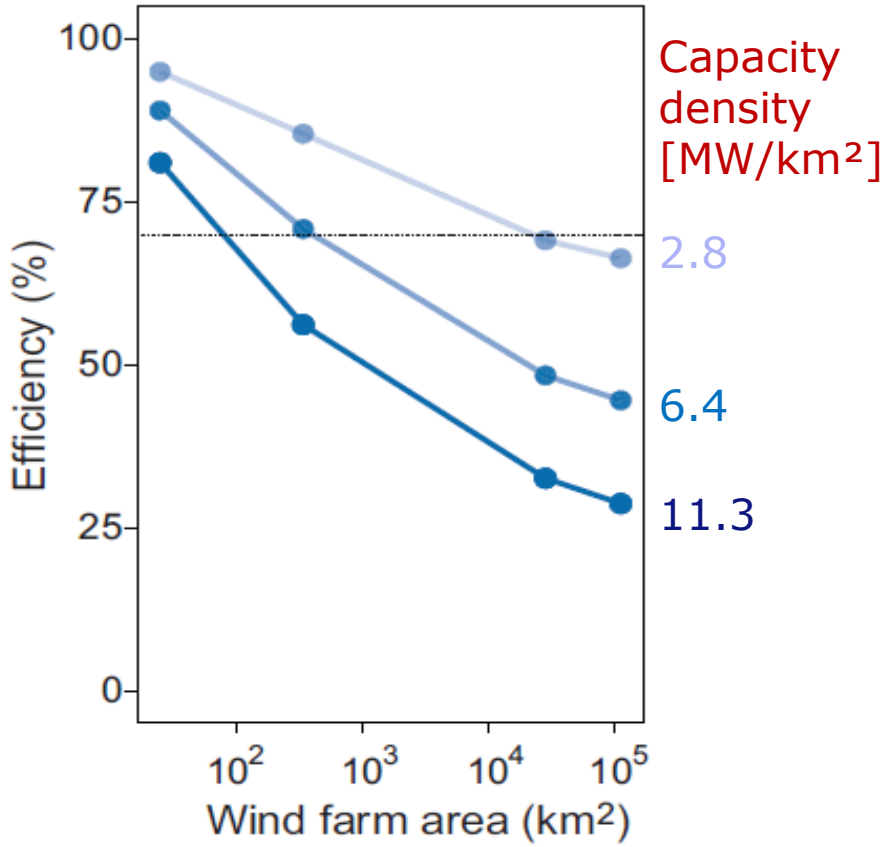
	NET Capacity Factor
Site 1 = 230 km^2 , CD = 2.6 MW/km^2 ➔ wake loss = 6.9%	36.9%
Site 2 = 82 km^2 , CD = 7.2 MW/km^2 ➔ wake loss = 8.7%	39.0%
Site 3 = 160 km^2 , CD = 3.7 MW/km^2 ➔ wake loss = 9.4%	33.2%

Considering an increase from 600MW to 3000MW (**3GW**)

Similar to Bornholm (DK) Wind Farm Cluster

	NET Capacity Factor
ES 1 = 1150 km^2 , CD = 2.6 MW/km^2 ➔ wake loss = 16%	33.5%
ES 2 = 410 km^2 , CD = 7.2 MW/km^2 ➔ wake loss = 23%	33.4%
ES 3 = 800 km^2 , CD = 3.7 MW/km^2 ➔ wake loss = 18%	30.3%

Research findings (Volker et al, 2017):



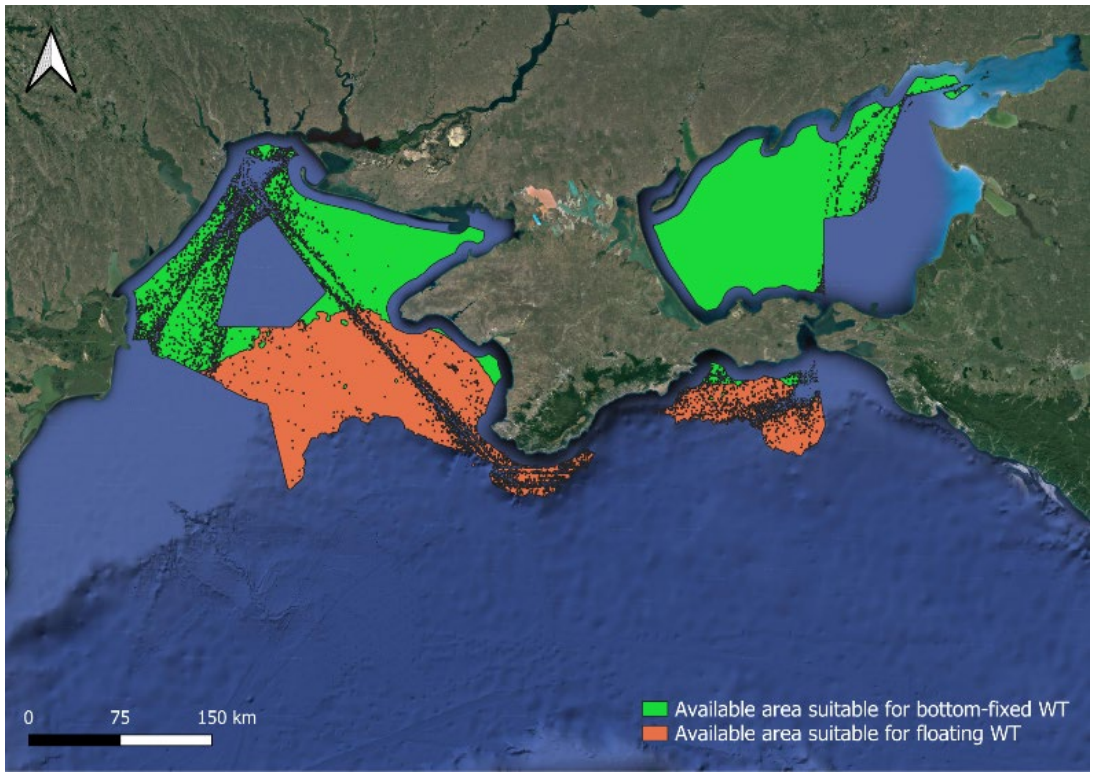
Volker, P, Hahmann, AN, Badger, J & Ejsing Jørgensen, H 2017, 'Prospects for generating electricity by large onshore and offshore wind farms: Letter', *Environmental Research Letters*, vol. 12, no. 3, 034022

Summary

- Wind climate and wind resource assessed using freely available DTU's Global Wind Atlas
- Assessment of suitable areas based on freely available global datasets of environmentally sensitive areas, shipping activity, wind power density, and water depth.
  - Check against other data sources showed consistency with suitability assessment
  - Other data sources point to factors to be considered in more depth for specific site development
- 3 Hypothetical Windfarms investigated in terms of
  - Annual Energy Production
  - Levelized Cost of Energy

Conclusion 1

	Bottom-fixed wind turbines	Floating wind turbines
Available Areas for Offshore Wind Farms	~30,000 km^2	~20,000 km^2
Guiding Maximum Capacity	~30 GW	~20 GW



Conclusion 2

	Site 1 Northern Black Sea	Site 2 Sea of Azov
Capacity Factor 600 MW Wind Farm	36.9 %	39 %
Capacity Factor 3 GW Wind Farm	33.5 %	33.4 %
LCOE [EUR / MWh]	98 – 142	91 – 131

	Site 3 West of Crimea
Capacity Factor 600 MW Wind Farm	33.2 %
Capacity Factor 3 GW Wind Farm	30.3 %
LCOE [EUR / MWh]	223 – 294

Table 2: Main characteristics of the wind farm sites

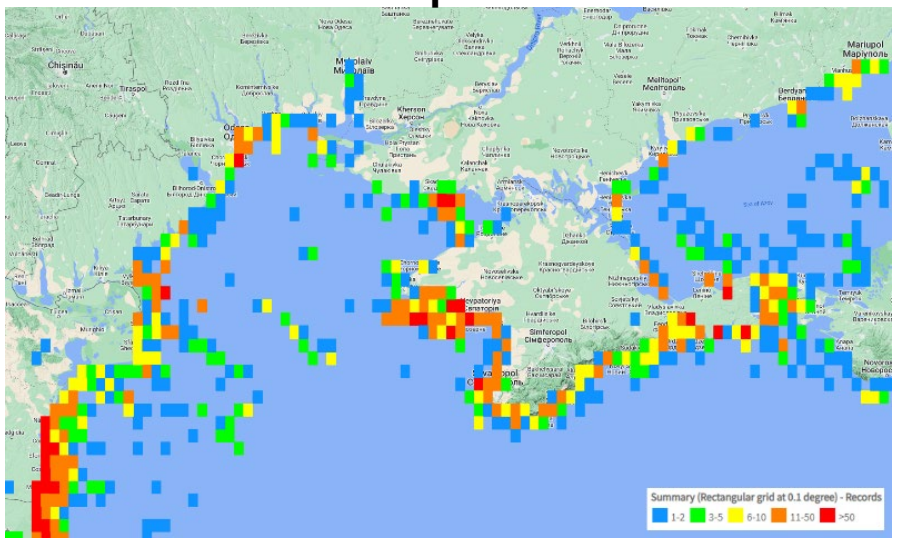
Characteristic	Site 1	Site 2	Site 3
Average water depth	25 m	8 m	55 m
Distance to shore	15.3 km	13.7 km	45.9 m
Distance to port	124 km (Odessa)	112 km (Mariupol)	161 km (Odessa)
Mean wind power density	602 W/m²	755 W/m²	549 W/m²

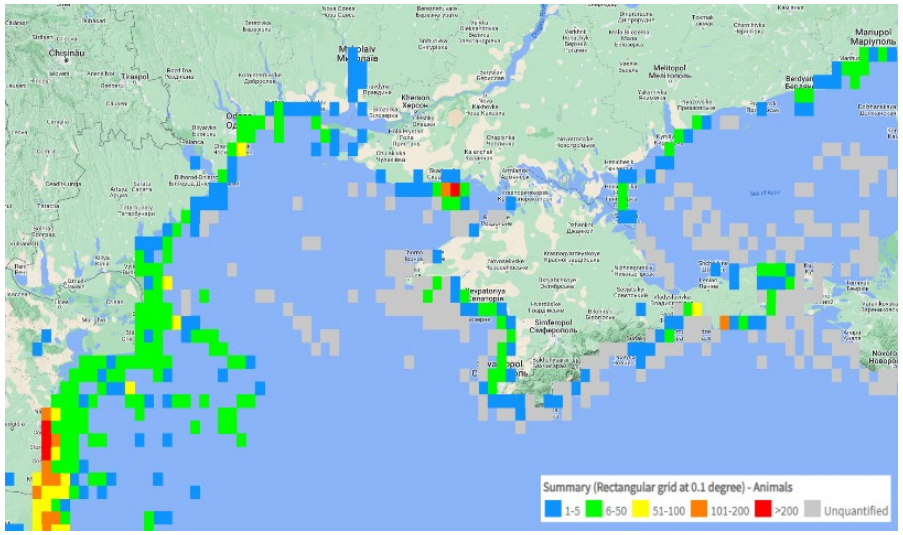
Figure 22: *Site locations in Ukraine*

Extra Slides

Comparison against other datasets of sensitive areas

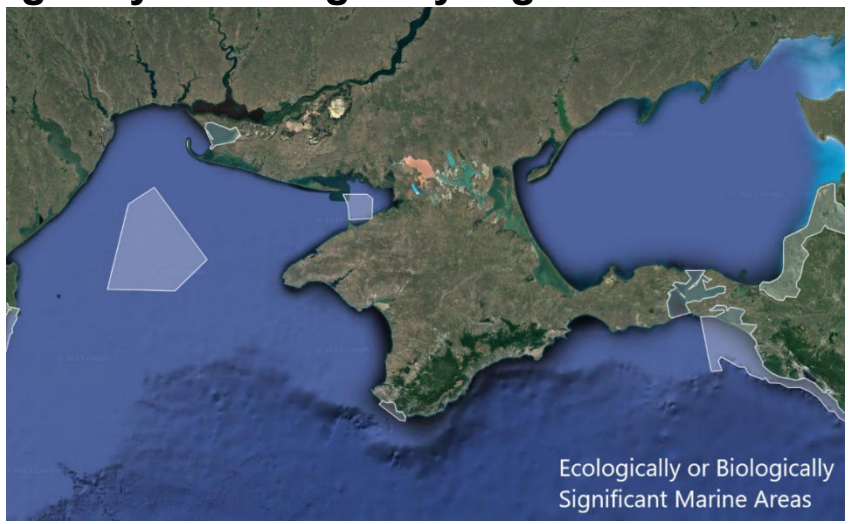
Grid representation of marine mammals as records and as animals





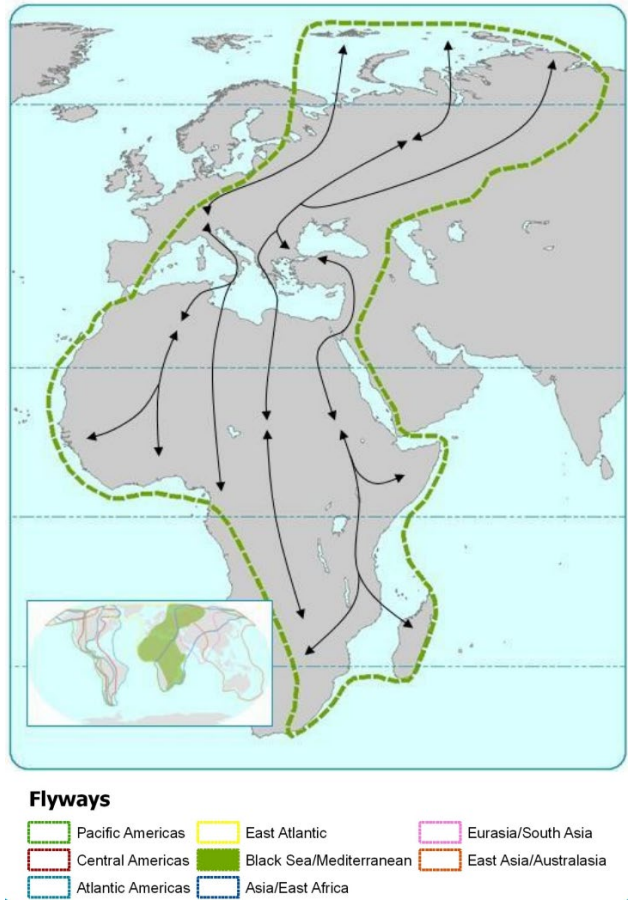
Source: OBIS-SEAMAP, https://seamap.env.duke.edu/species/179913

Ecologically of Biologically Significant Marine Areas



Source: EBSA, https://www.cbd.int/ebsa/

Bird Flyways



Source: BirdLife, http://datazone.birdlife.org/userfiles/file/sowb/flyways/5_Mediterranean_Black_Sea_Factsheet.pdf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