X THE PLACE OF USEFUL LEARNING

University of Strathclyde Engineering

Long-Term Variation of Wave Climate and Energy in the UK

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Matt Lewis, Wood PLC. & Bangor University

June 2025

Wave Energy

Global potential of Marine Energies

Form	Annual generation
Tidal energy	>300 TWh
Marine current power	>800 TWh
Salinity gradient (Blue Energy)	2,000 TWh
OTEC	10,000 TWh
Wave energy	8,000–80,000 TWh

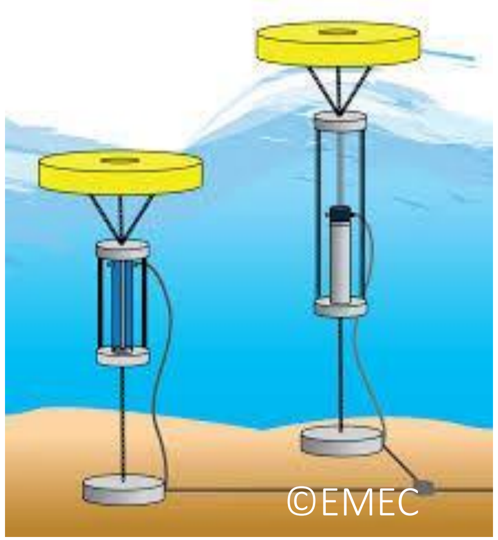
Source: IEA-OES, Annual Report

The world's electricity consumption is approximately 23,900 TWh

Wave Energy

Advantages of Wave Energy:

- ✓ Predictable
- ✓ Endless
- ✓ High density
- ✓ Low visual and environmental impacts
- ✓ Broad geographic viability
- ✓ Adding to the diversity (+ co-location)



Usages:

- ✓ **Power generation**
- ✓ Desalination
- ✓ Hydrogen production
- ✓ Pumping and heating processes
- ✓ Coastal protection

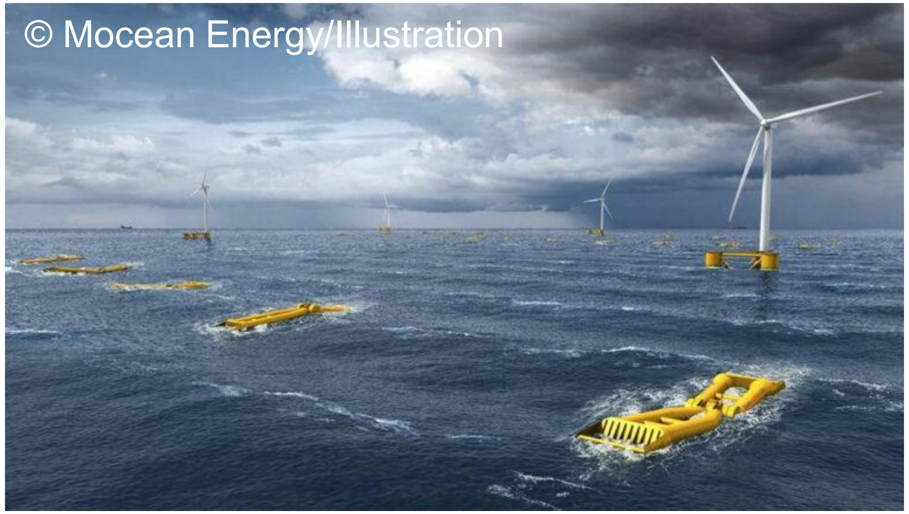
Wave Energy

Wave farms contribute to mitigating climate change by two means:

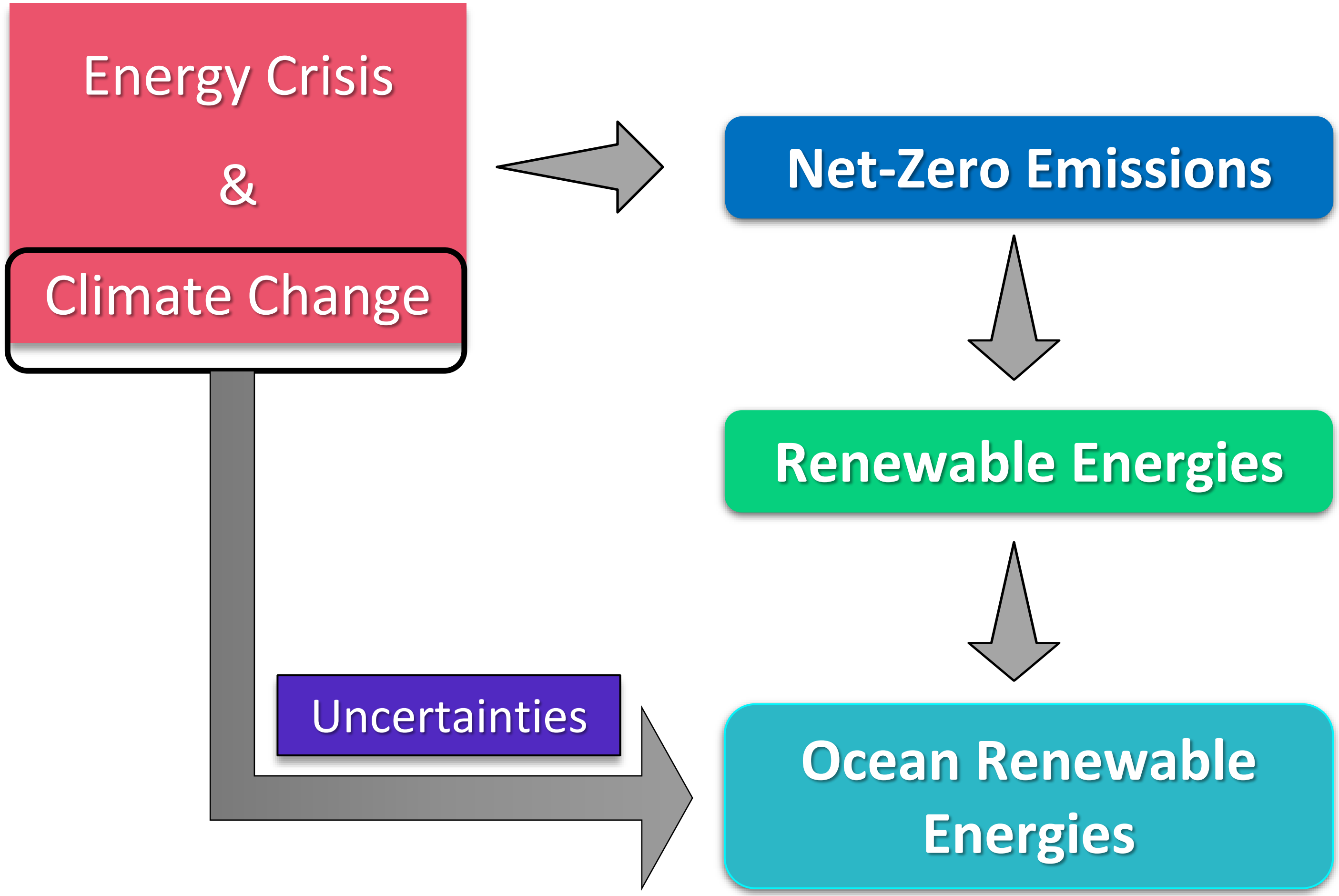
1) Cause: by bringing down carbon emission
2) Effect: By reducing coastal erosion (which has caused by sea level rise and increased storminess due to climate change)

Another major advantage: Adaptation!

Wave farms typically are floating structures → Adapt naturally to sea level rise



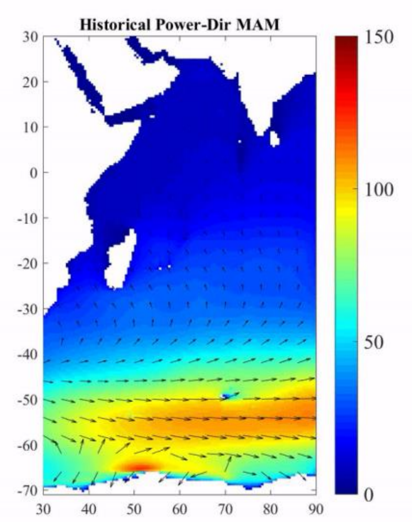
Wave Energy


Energy Crisis
&
Climate Change
Net-Zero Emissions
Renewable Energies
Uncertainties
Ocean Renewable Energies

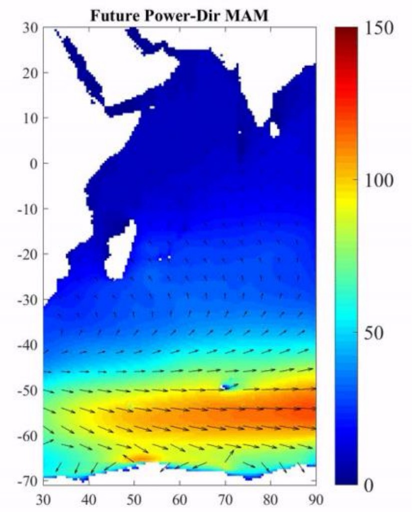
Previous works

Seasonal Means of wave power (kW/m)

Historical



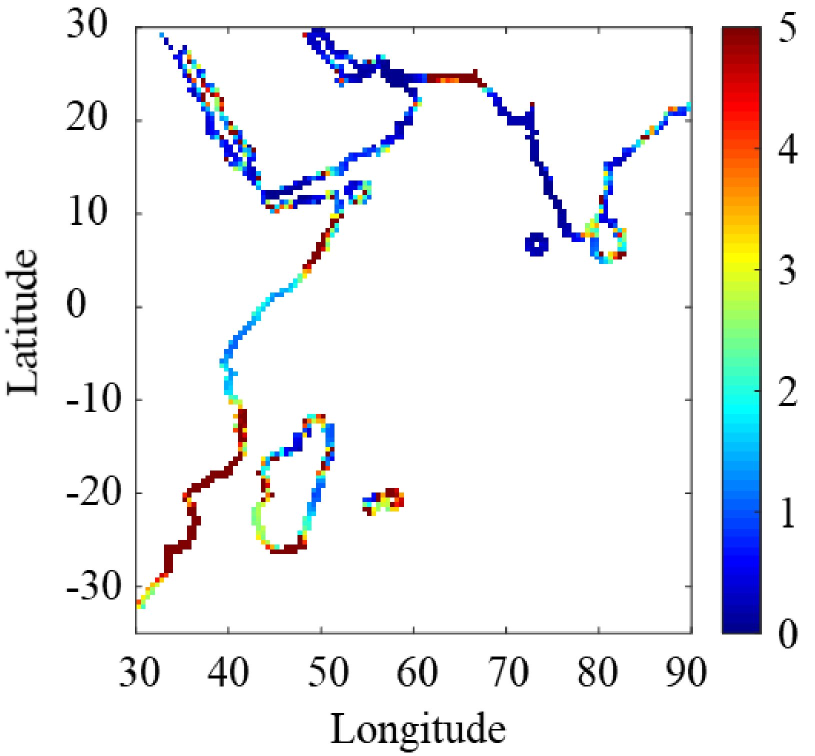
Future



Climate Stability Index (CSI)

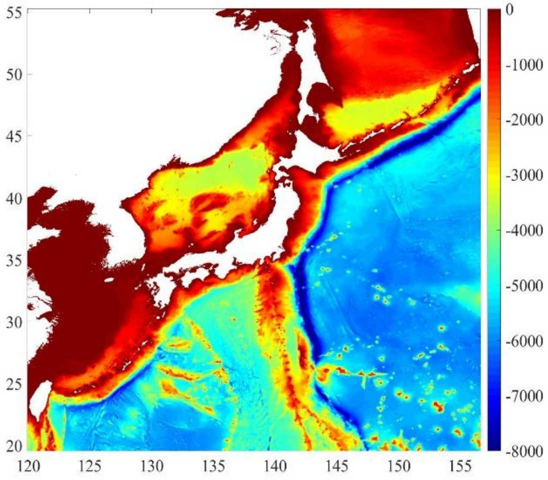
Higher stability:
- Lower Historical Monthly variability (MVI_H)
- Lower change in Future Monthly variability (MVI_F- MVI_H)
- Lower Relative Future Change ($\Delta P/P$)

$$CSI_p = \frac{1}{\left| (MVI_F - MVI_H) \times MVI_H \times \frac{(P_F - P_H)}{P_H} \right|}$$

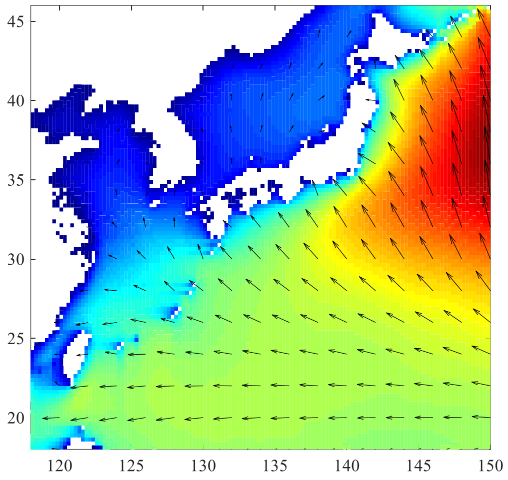


Previous works

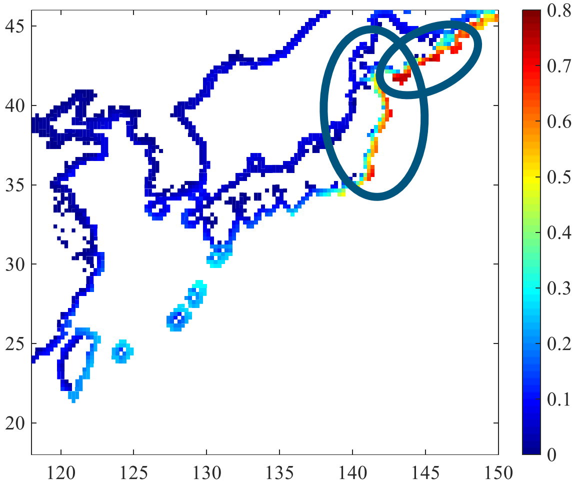
Depth (m)

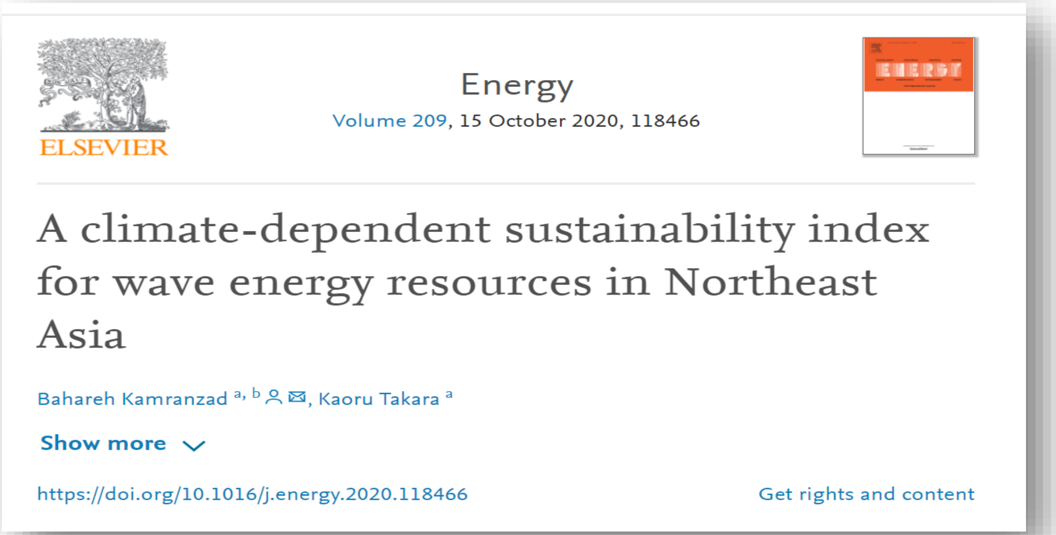


Wave power (kW/m)



A proposed **Sustainability Index (SI)**

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A climate-dependent sustainability index for wave energy resources in Northeast Asia

Bahareh Kamranzad [a, b], Kaoru Takara [a]

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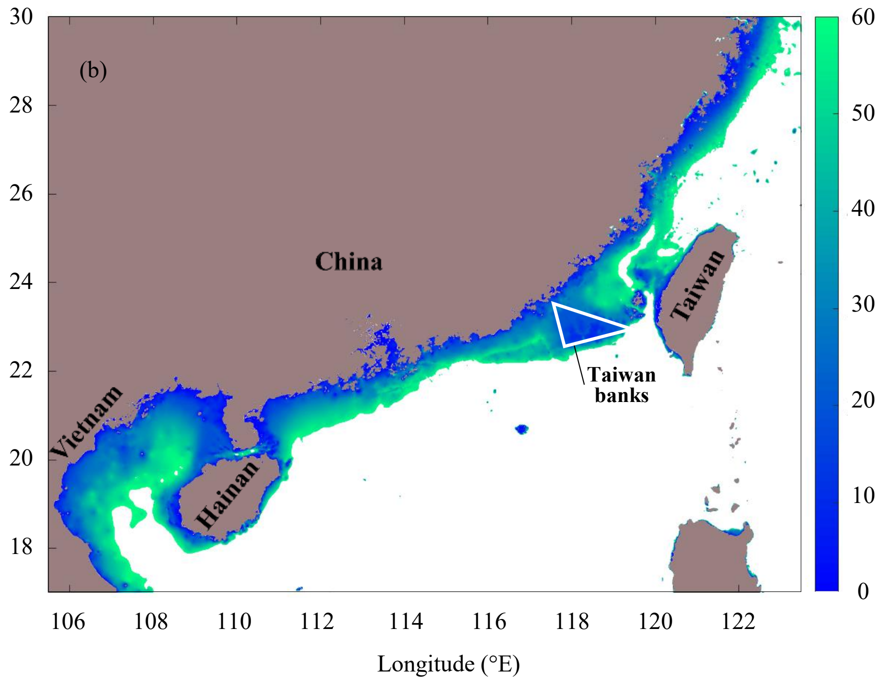
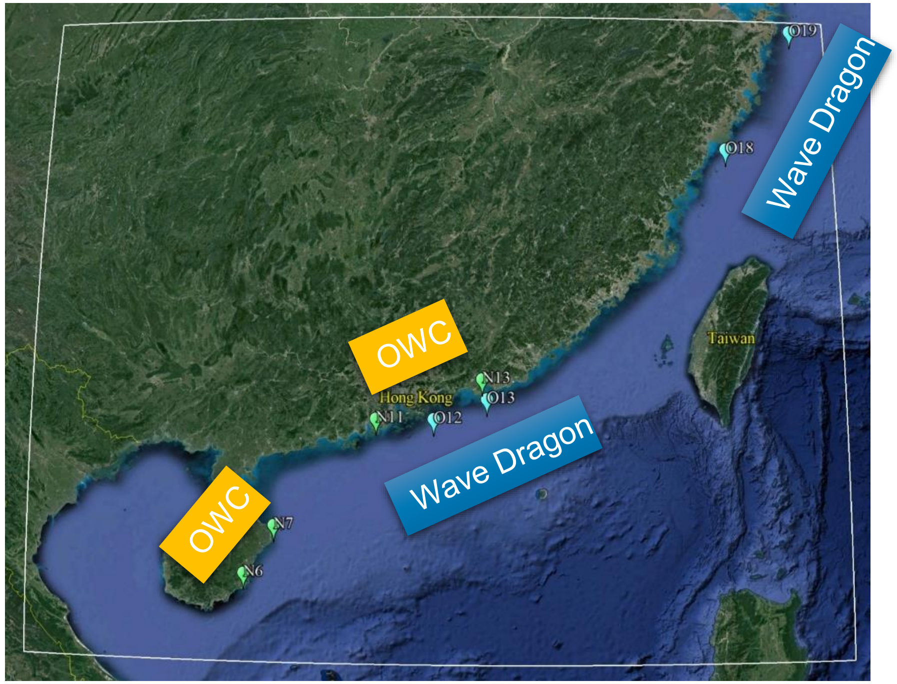
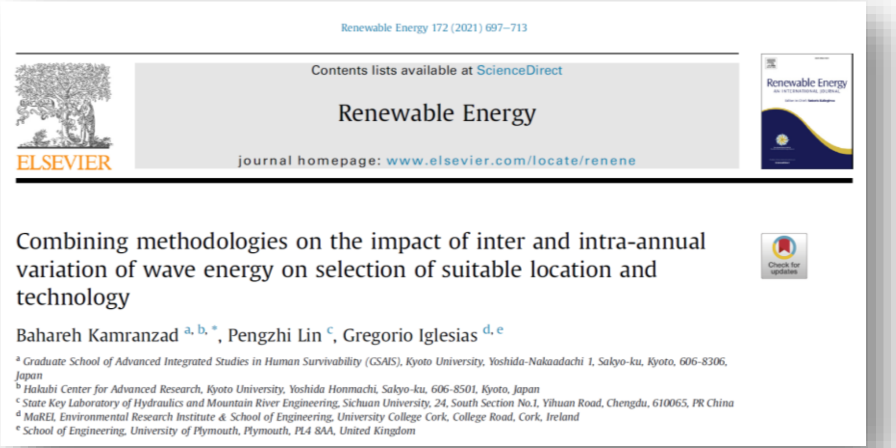
Previous works



Bathymetry (depths in m) in the areas with depth below 60 m

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journal homepage: www.elsevier.com/locate/renene

Combining methodologies on the impact of inter and intra-annual variation of wave energy on selection of suitable location and technology

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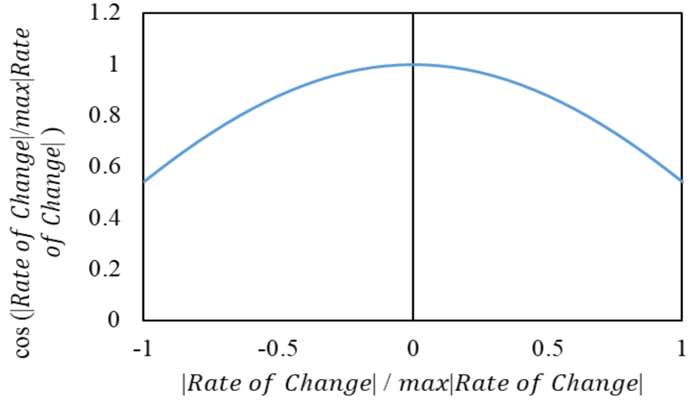
Previous works

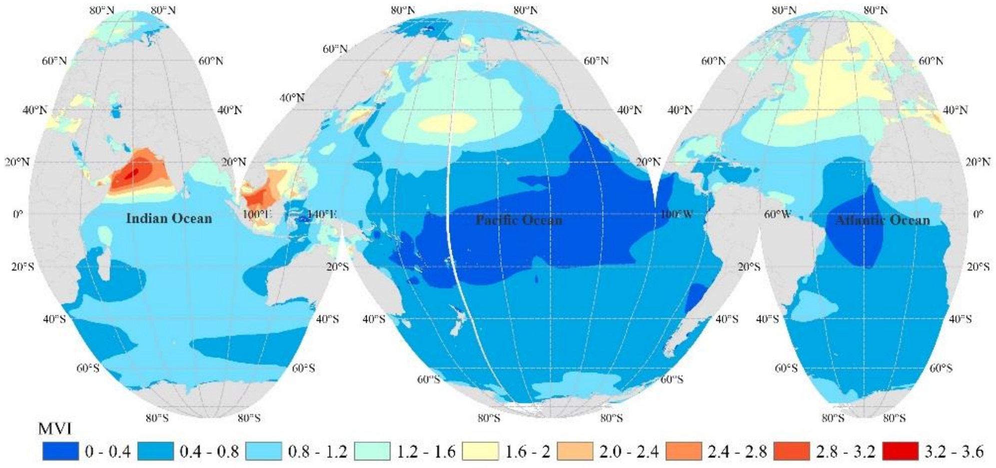
Priority coasts considering the variation and change in resources

Ideal condition:

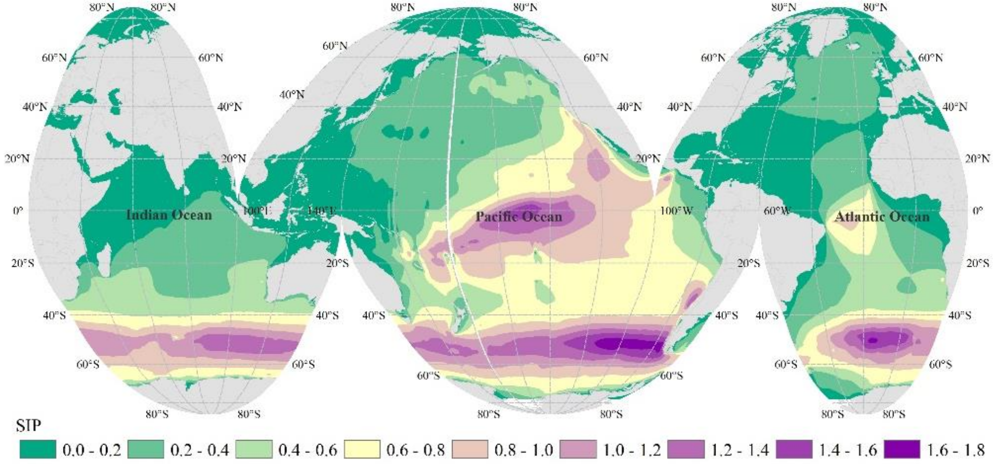
- Highest P
- Lowest MVI
- Lowest rate of change (negative or positive)



$$SI_P = \frac{\dfrac{P_{annual\ mean}}{\max(P_{annual\ mean})} \times \cos\dfrac{Rate\ of\ change}{max|Rate\ of\ change|}}{MVI}$$



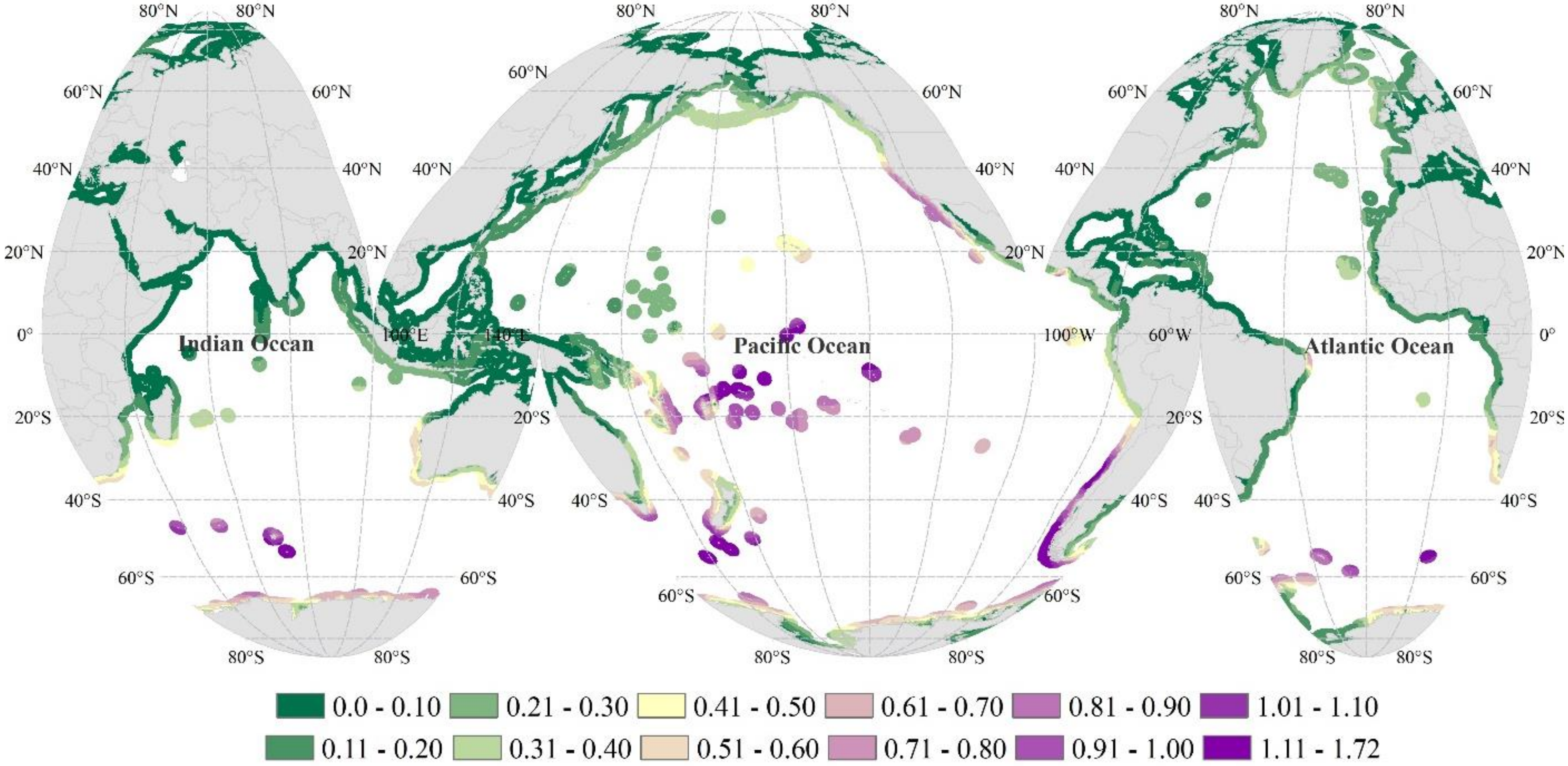
Monthly Variability Index (MVI)



Sustainability Index (SI_p)

Previous works

Priority coasts considering the variation and change in resources



Motivation

- Wave energy holds great potential as a renewable energy source for the UK, but its successful integration into the energy mix requires a thorough understanding of its variability across different time scales.
- This study examines ocean wave climate variations to assess wave energy sustainability, analysing long-term trends to identify shifts over decades, decadal variability to capture periodic fluctuations, and inter-annual patterns to understand predictability in various time scales.

Method

ECMWF ERA5 re-analysis wave data were used to calculate the wave characteristics and power around the UK for 80 years period (1943-2022).

The data has spatial resolution of 0.5° (in both direction) and temporal resolution of 1 hr.

$$P = \frac{\rho g^2}{64\pi} H_{m0}^2 T_e$$

P = wave energy flux per unit of wave-crest length

H_{mo} = the significant wave height

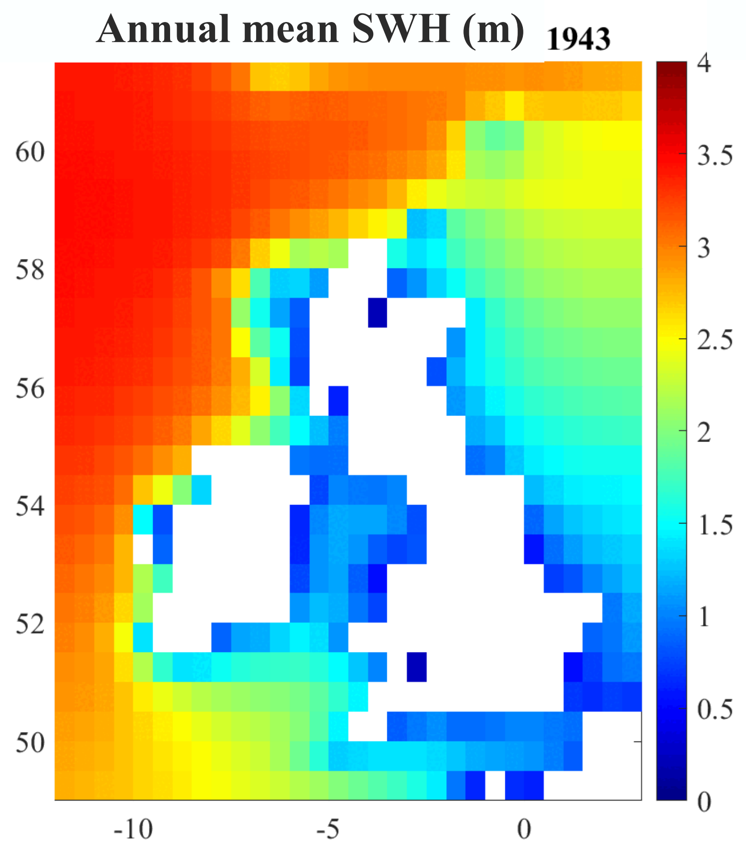
T_e = the wave energy period

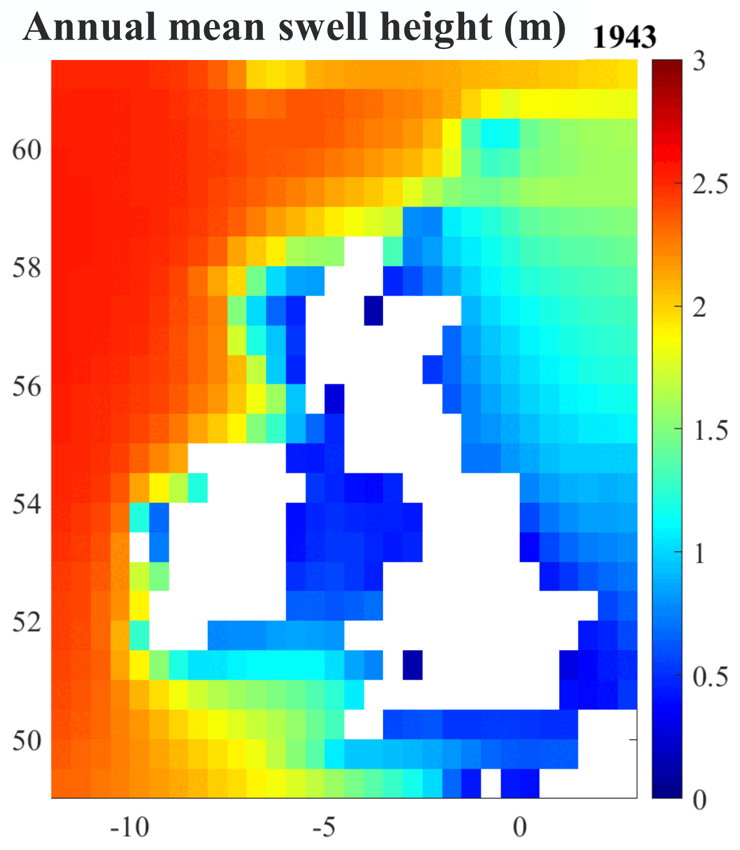
ρ = water density

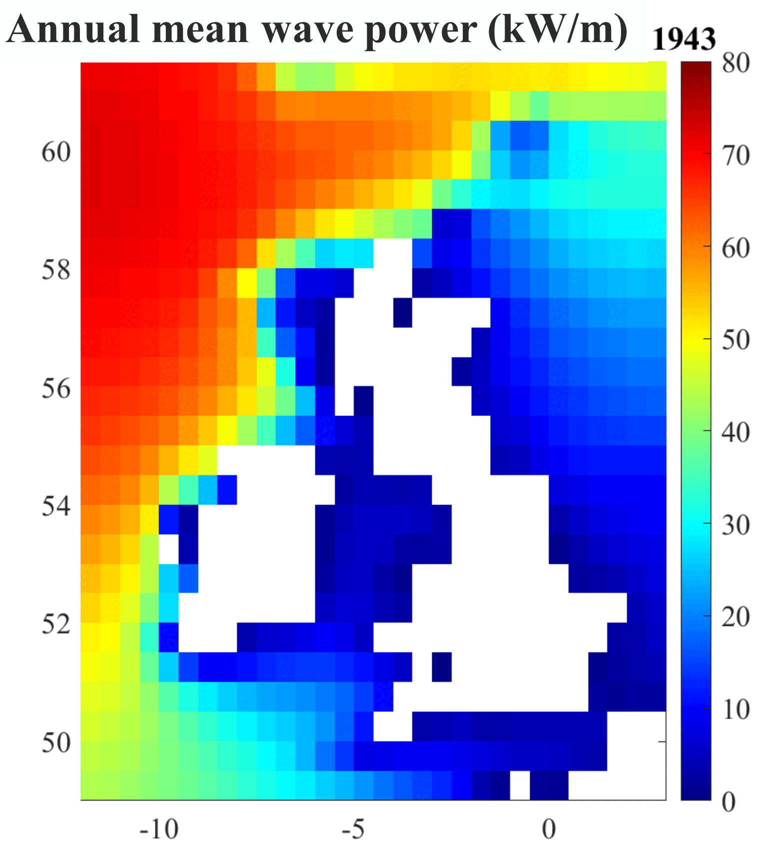
g = the acceleration by gravity

Results

Annual Mean Wave Power around the UK for 80 years (1943-2022)

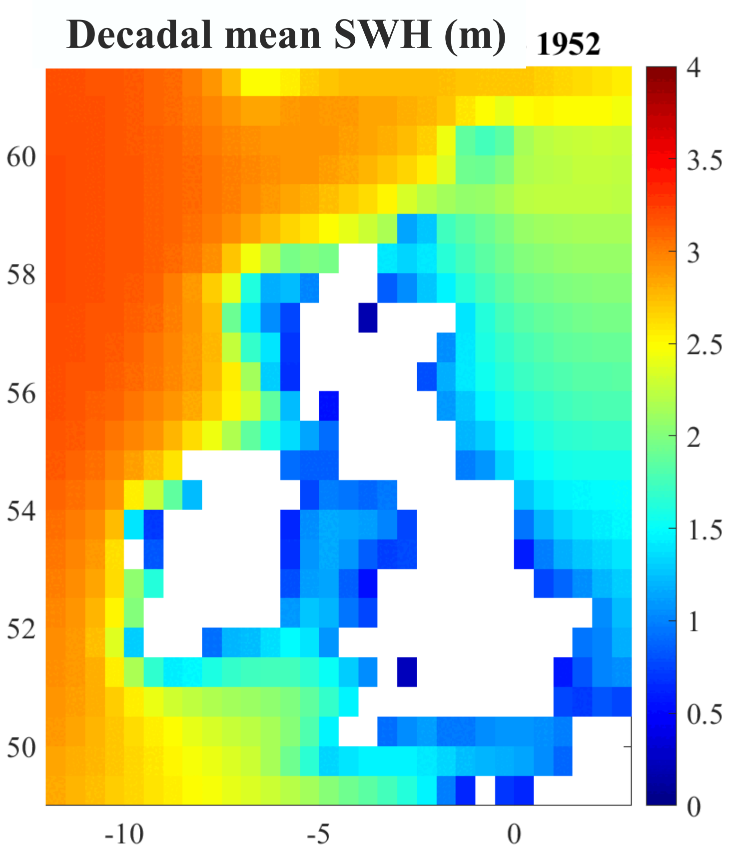


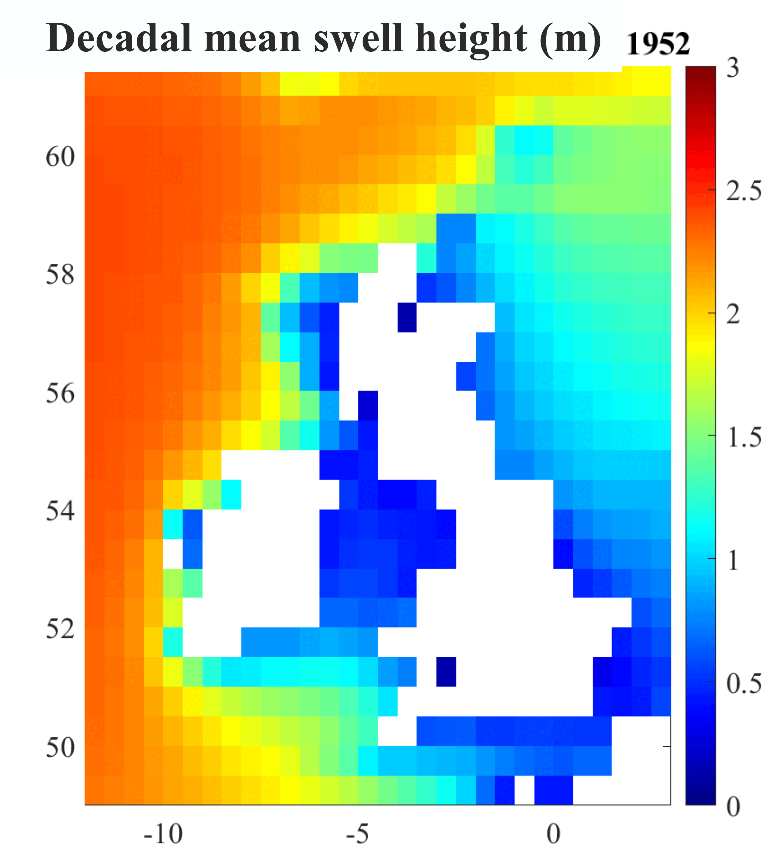


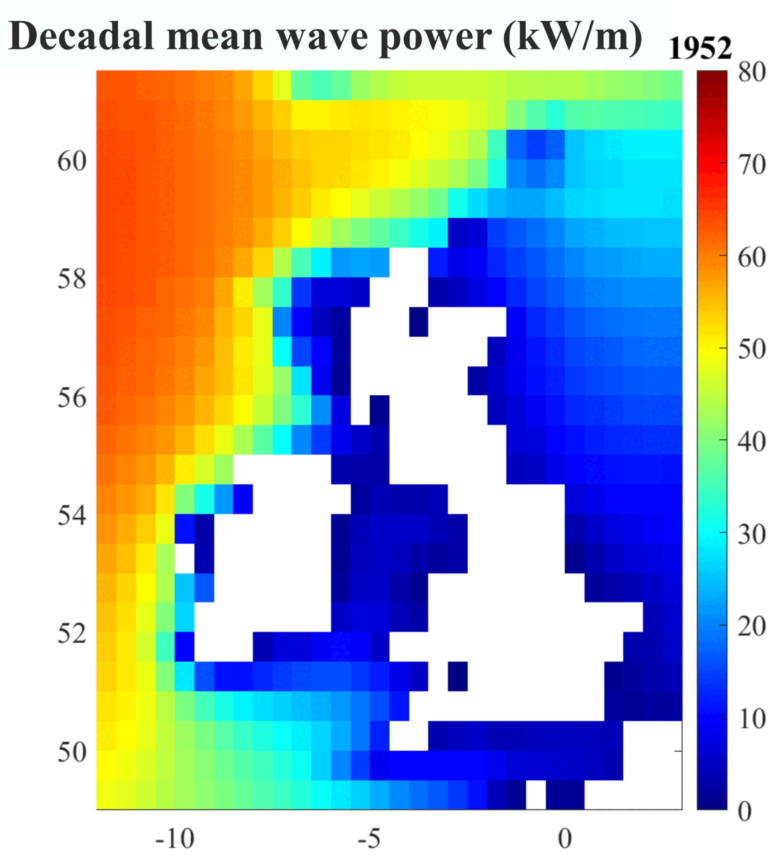


Results

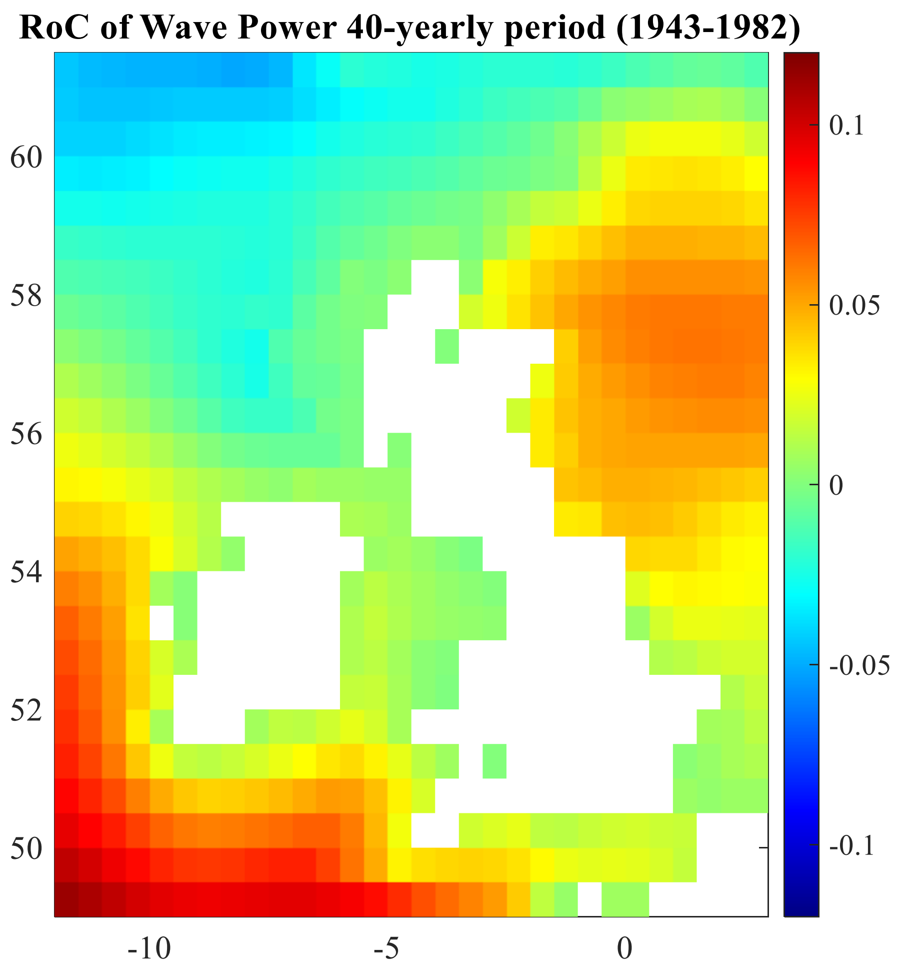
Decadal Mean Wave Power around the UK for 80 years (1943-2022)

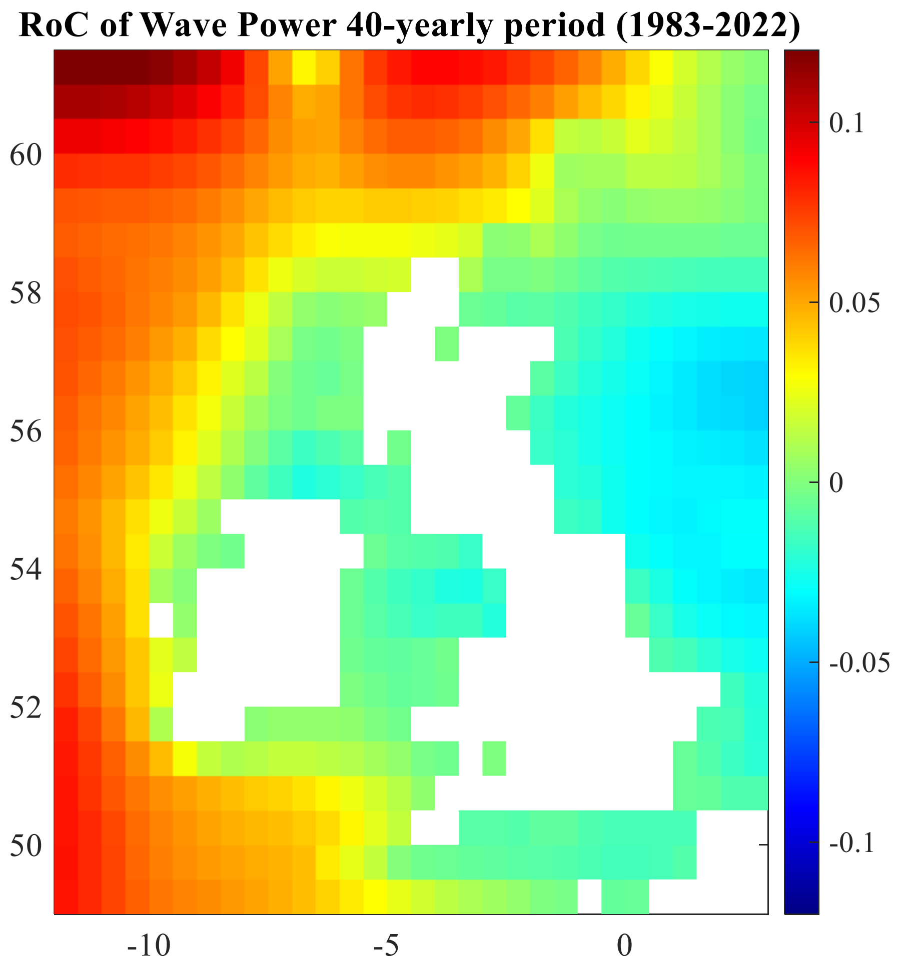






Rate of Change (RoC) in annual mean wave power - 40 yearly (kW/m per year)

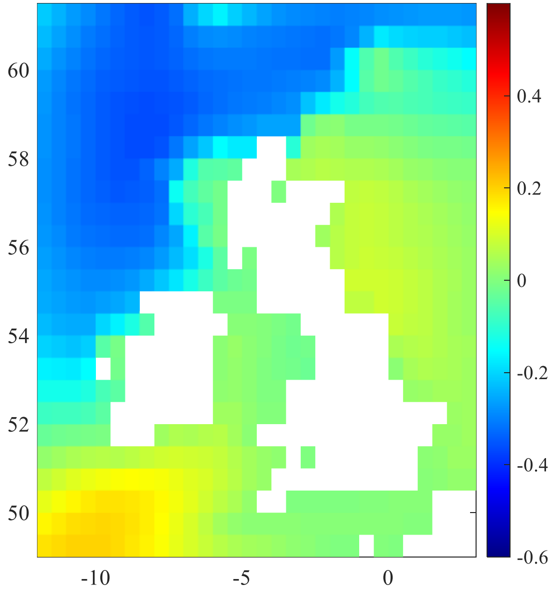




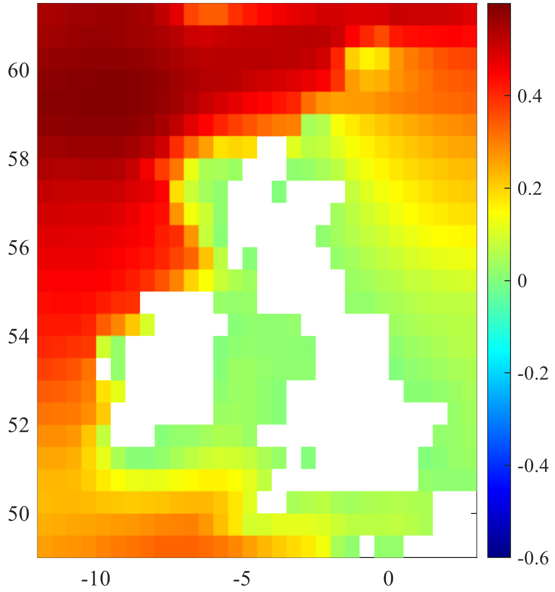
Results

Rate of Change (RoC) in annual mean wave power - 20 yearly (kW/m per year)

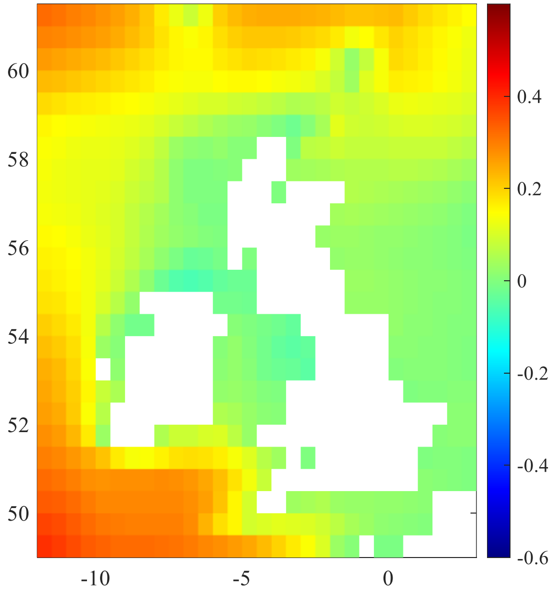
RoC of Wave Power 20-yearly period (1943-1962)



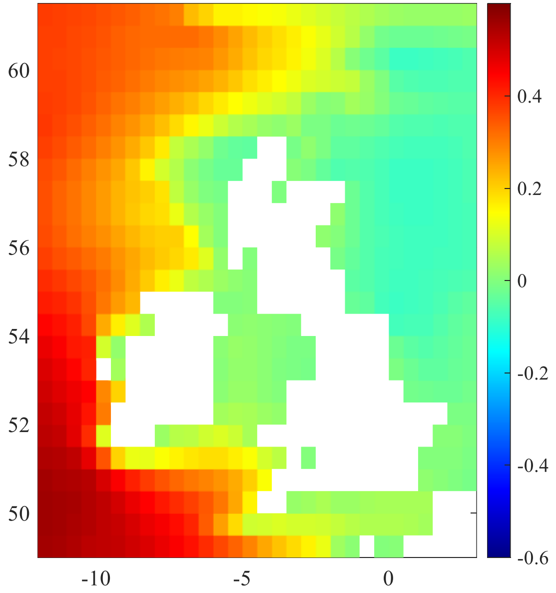
RoC of Wave Power 20-yearly period (1963-1982)



RoC of Wave Power 20-yearly period (1983-2002)

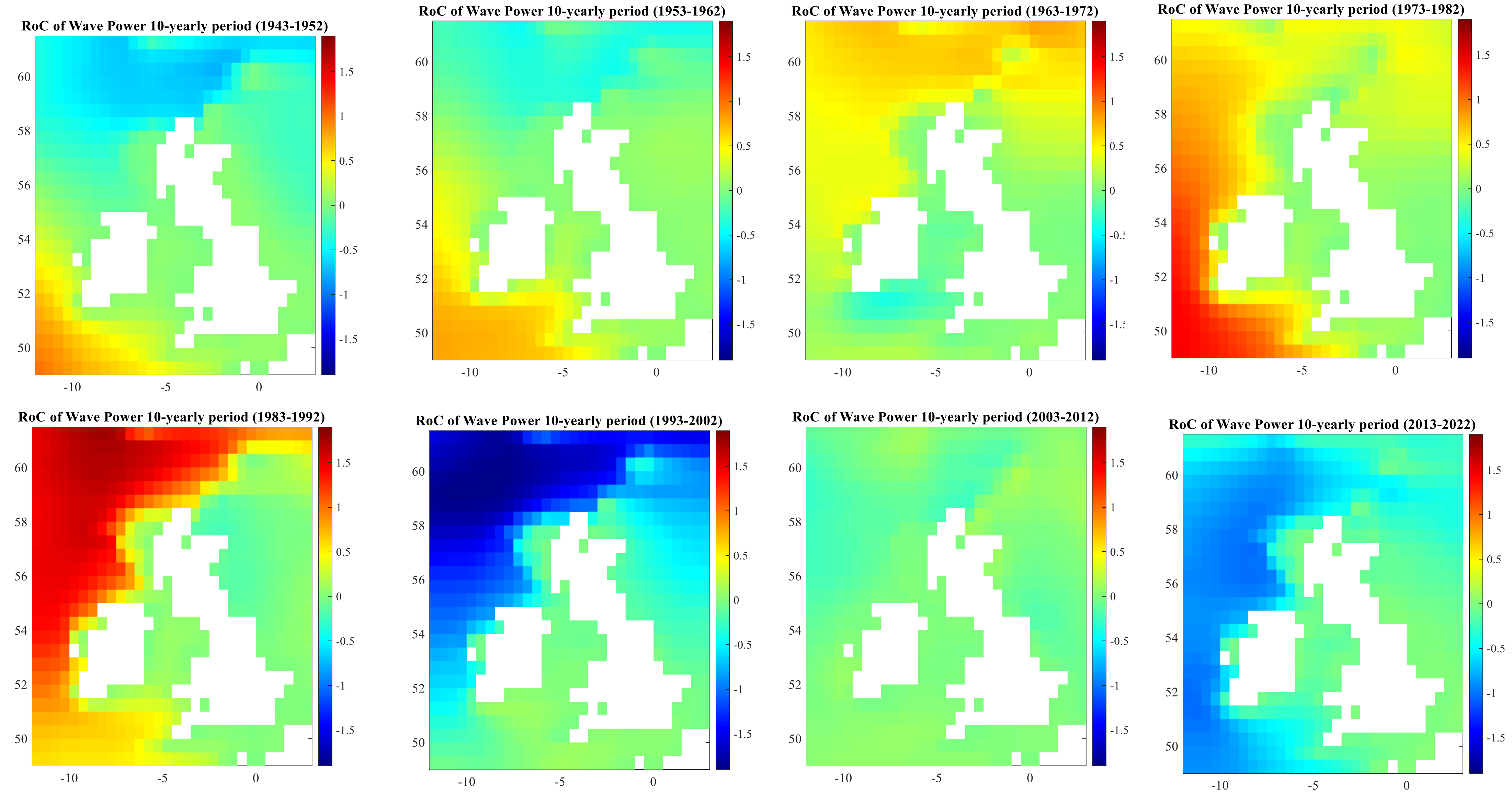


RoC of Wave Power 20-yearly period (2003-2022)



Results

Rate of Change (RoC) in annual mean wave power – 10 yearly (kW/m per year)



Conclusions

- The sustainability of wave energy around the UK depends on understanding its variability across different time scales.
- Long-term trends due to climate change, decadal fluctuations due to periodic patterns, and intra-annual variations impact predictability and planning.

  >> It is essential to choose a suitable interval for wave energy resource assessment. Contrary to IEC's recommendation for a minimum of 10 years for wave energy assessment, our results showed that assessment period can lead to an over/under-estimation of wave power.

- Recognising regions with consistent wave energy potential can help optimise site selection, while accounting for short-term variability, including extreme events, is crucial for ensuring the resilience of wave energy systems.
- To ensure the long-term sustainability of wave energy, it is essential to integrate climate variability into the planning, design, and management of wave energy projects. This approach enhances the reliability of wave energy systems and strengthens their role in the UK's renewable energy mix amidst climate change challenges.

Thanks for your attention

Any Questions?