Hybrid renewable energy system for maritime applications

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Data collection from the ocean

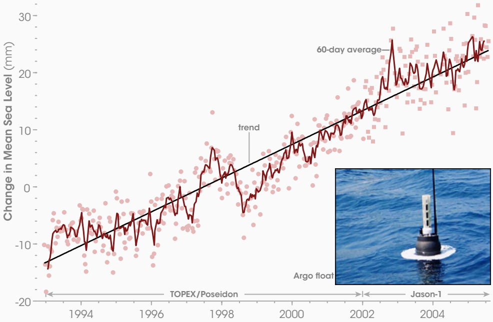

Figure 1: Verification of global sea-level rise model with buoy measurement [1]

Environmental data collected from the sea is important for us to better understand our ocean.

Data collection on the move

Figure 2: Global distribution of buoys of National Data Buoy Center

Collect data on the move would significantly increase the spatial coverage of dataset.

Data collection on the move

Figure 3: Global distribution of buoys of National Data Buoy Center

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Power supply is the major issue for long-term unattended operation of ocean going platforms.

Hybrid renewable energy system

Renewable energy system is a potential solution that harvest sustainable resources such as wind, wave and solar energy from ambient environment.

Hybrid renewable energy system, if well designed, can harness power from multiple resources at same time to mitigate the variation issue.

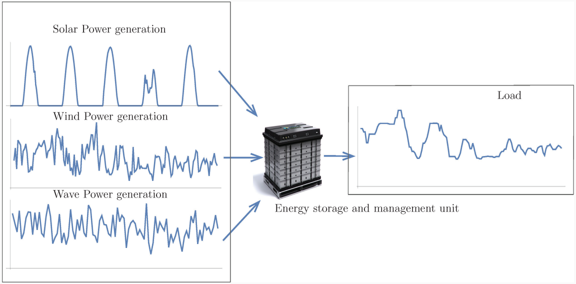

Figure 4: Structure of hybrid renewable energy system

Renewable power on the sea

The researches on renewable energy system are mostly focus on a single operation location. None of state-of-art research on renewable energy system design is able to handle this problem.

Methodology: energy from resource to load

Energy model: Resource $\rightarrow$ Transducer $\rightarrow$ Load

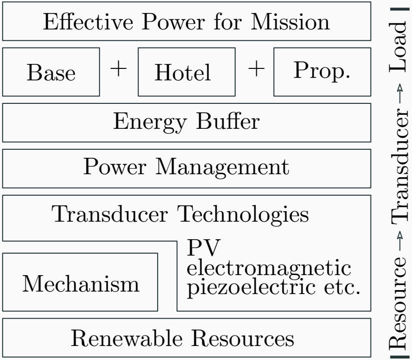

Figure 5: Energy flow in hybrid renewable energy system

In this study, we explore the deign and management of hybrid renewable energy system using multi-scale energy model for the power subsystem on ocean going platforms.

$$P_{solar} + P_{wind} \geq P$$

Global yearly analysis

Energy model

$$P_{solar} + P_{wind} \geq P \tag{1}$$

with Solar and wind energy

$$P_{solar} = \eta_s G_0 A_s, \quad P_{wind} = \frac{1}{2}\rho C_p(\lambda) A_w u^3 \tag{2}$$

we will have

$$\boxed{\eta_s G_0} \cdot A_s + \boxed{\frac{1}{2}\rho C_p(\lambda) u^3} \cdot A_w \geq P \tag{3}$$

written as

$$\mathcal{P}_{solar} \cdot A_s + \mathcal{P}_{wind} \cdot A_w \geq P \tag{4}$$

Global yearly analysis: global horizontal irradiance G_0

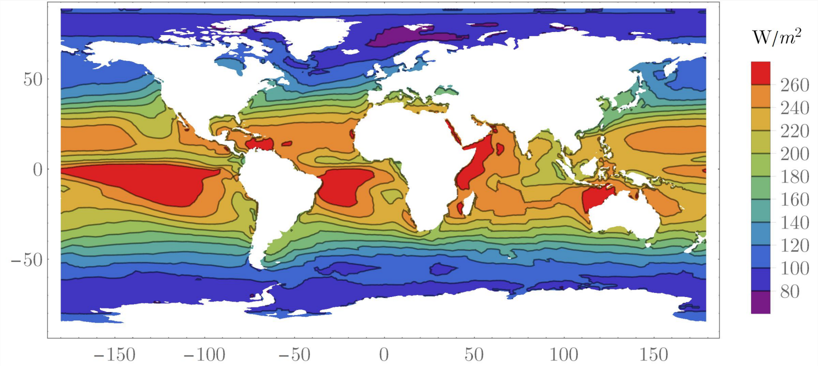

Figure 6: Global daily averaged horizontal radiation on the sea

Global yearly analysis: $\mathcal{P}_{solar}$

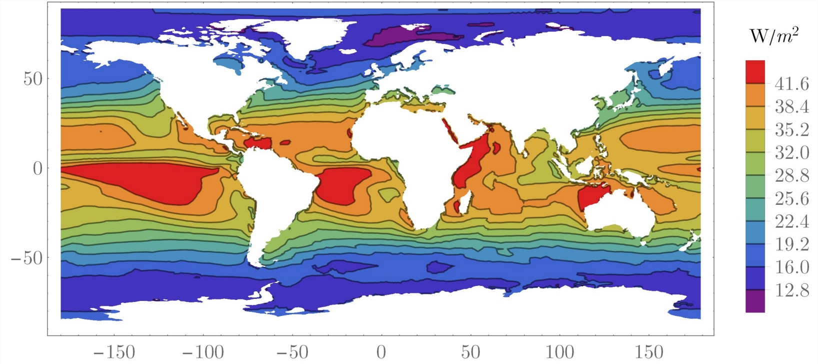

Figure 7: Global daily averaged horizontal radiation on the sea

Global yearly analysis: $\mathcal{P}_{wind}$

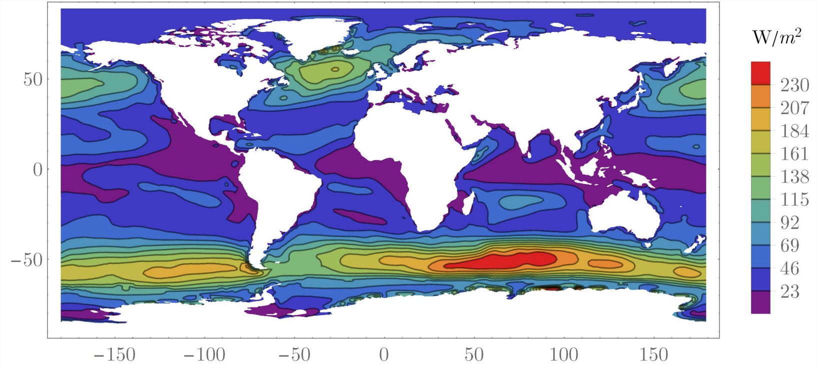

Figure 8: Global wind energy potential on the sea

Yearly based design

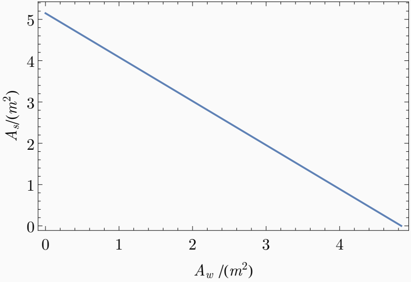

Figure 9: Sizing curve based on yearly model at 55N, 10E $P = 100W$

Graphically, the constraint on energy model can be shown as a straight line.

$$\mathcal{P}_{solar} \cdot A_s + \mathcal{P}_{wind} \cdot A_w \geq P$$

Global yearly analysis: on three major routes

Three example routes for yearly power supply potential assessment from renewable resources: North America to Asia, Middle East to North America and, Europe to North America.

Figure 10: Example routes for yearly power potential assessment

Global yearly analysis: on three major routes

The total energy can be collected on ocean going platforms are limited by the space. For different shapes of platforms, the total power supply potential in shown below:

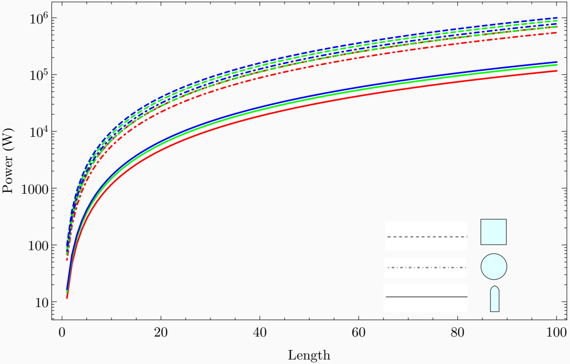

Figure 11: Power supply potential of wind solar hybrid system on three main routes

Global yearly analysis: matching with propulsion power

How many percentage of those power can be used for propulsion on the sea? We use empirical method to estimate resistance and propulsion power of ships at various length. The ratio between renewable supply to propulsion load is shown below:

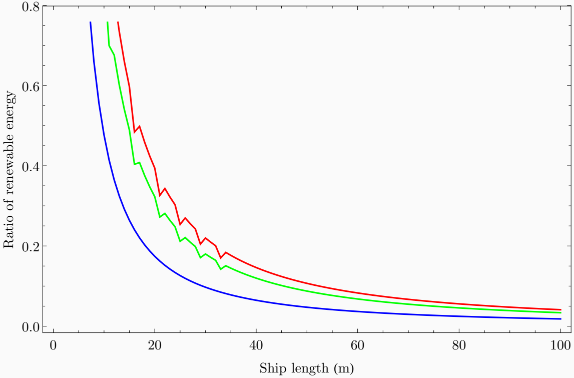

Figure 12: Propulsion power contribution

Monthly analysis: underlying complimentary between resources

The hybrid renewable energy system mitigate the effect of uncertainty by using two or more resource at the same time. Underlying complimentary feature between renewable energy resource is the basis of the concept of hybridization.

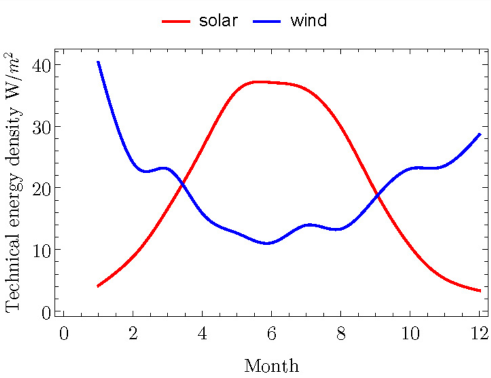

Figure 13: Monthly solar and wind energy power generation at 55N, 10E

Monthly global analysis: where complimentary can be found

The Kendall τ test is used to quantify the correlation between renewable energy resources. Negative number indicate disagreed trend between two resources. Here is monthly complimentary between solar and wind.

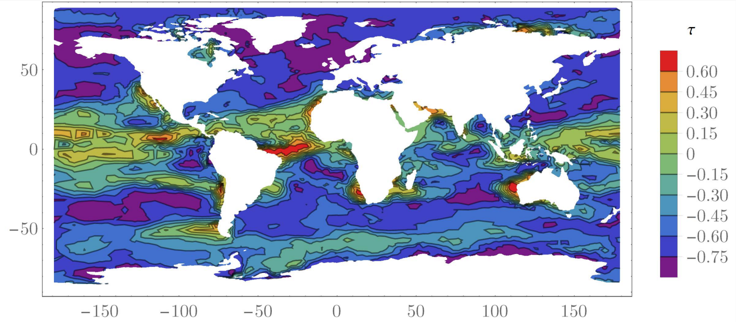

Figure 14: Global Kendall τ distribution

Yearly based design

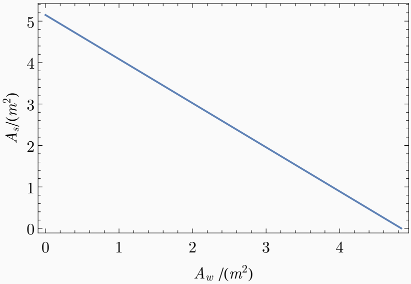

Figure 15: Sizing curve based on yearly model at 55N, 10E $P = 100W$

Graphically, the constraint on energy model can be shown as a straight line.

$$\mathcal{P}_{solar} \cdot A_s + \mathcal{P}_{wind} \cdot A_w \geq P$$

Monthly based design

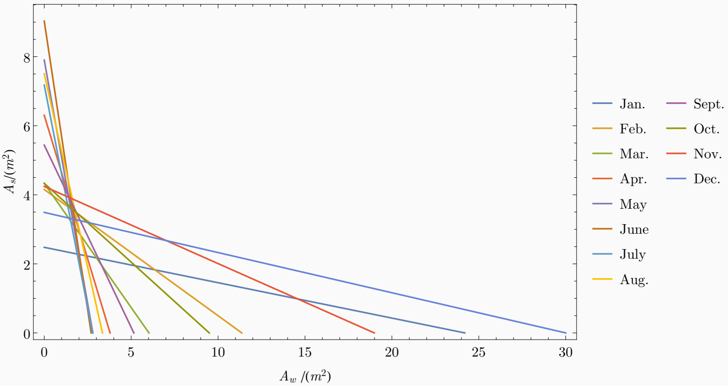

Figure 16: Sizing curves based on monthly energy balance

$$\mathcal{P}^i_{solar} A_s + \mathcal{P}^i_{wind} A_w \geq P,\ i = 1, \ldots, 12.$$

Monthly based design: from stationary to moving

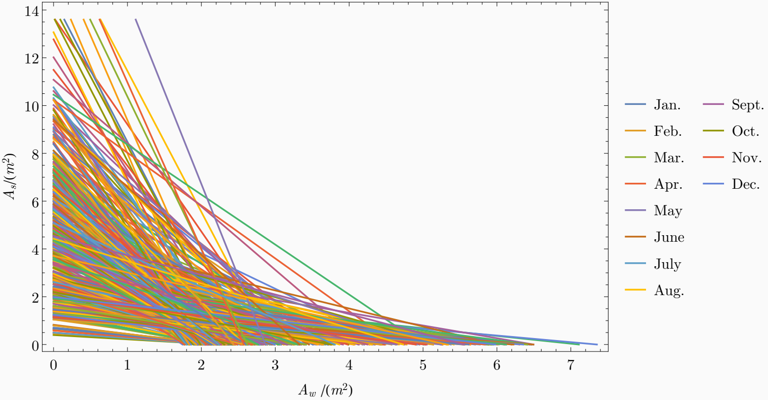

Figure 17: Sizing curve of the route from UK to NA

$$\mathcal{P}_{solar}^{i,p} A_s + \mathcal{P}_{wind}^{i,p} A_w \geq P,\ i = 1, \ldots, 12.$$

Conclusion and future work

Conclusion & future work

Two take-away information:

- The complimentary feature can be found on majority area of the sea between wind and solar energy.
- Power contribution of using hybrid renewable energy system for propulsion is higher for smaller craft.

Future work:

- Energy balance model in higher resolution
- Simulation with hindcast meteorological data

Questions?