WEC Optimization to Maximize Grid Economic Value and Avoided Emissions

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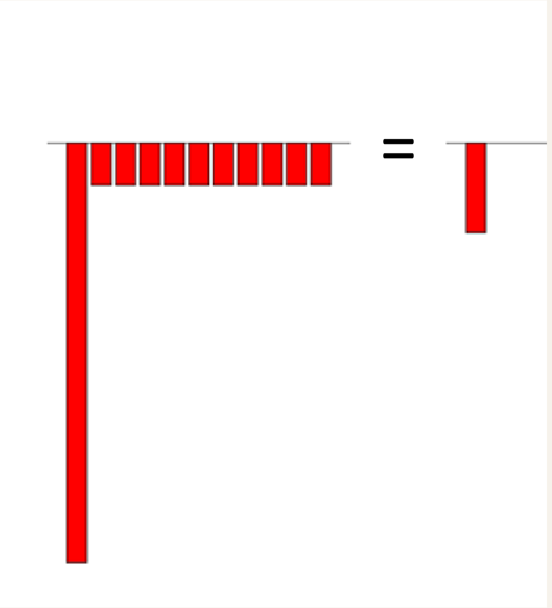
Motivation

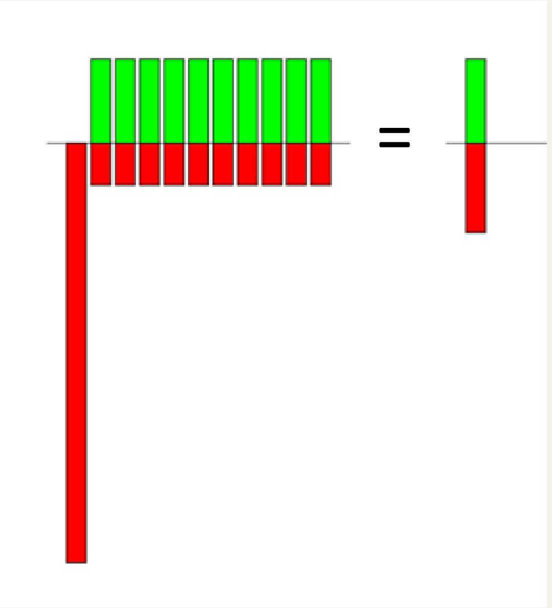
- Multidisciplinary design optimization (MDO) can reduce LCOE >50%
  - Strategy: derate PTO to get more consistent, less peaky power profile
- LCOE doesn't capture temporal/spatial value of WECs on the grid
  - Consistent vs peaky tradeoff depends on battery cost, transmission, seasonal complementarity (winter deficits with solar and/or electrified heat)
- Climate impact: WECs should displace fossil fuels, not other renewables
- Solution: perform MDO to **minimize cost and emissions on the grid**

Methods: Alternative Value Metrics

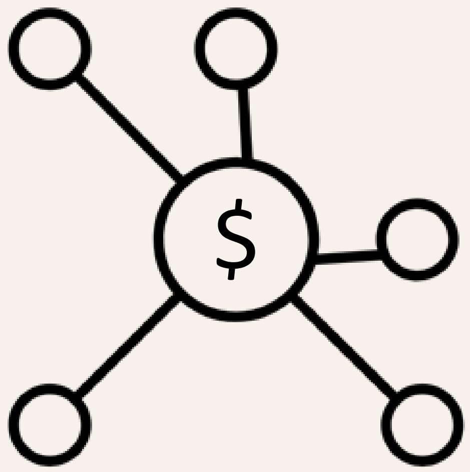
Standard: LCOE
Project levelized cost
(min revenue to offset costs)



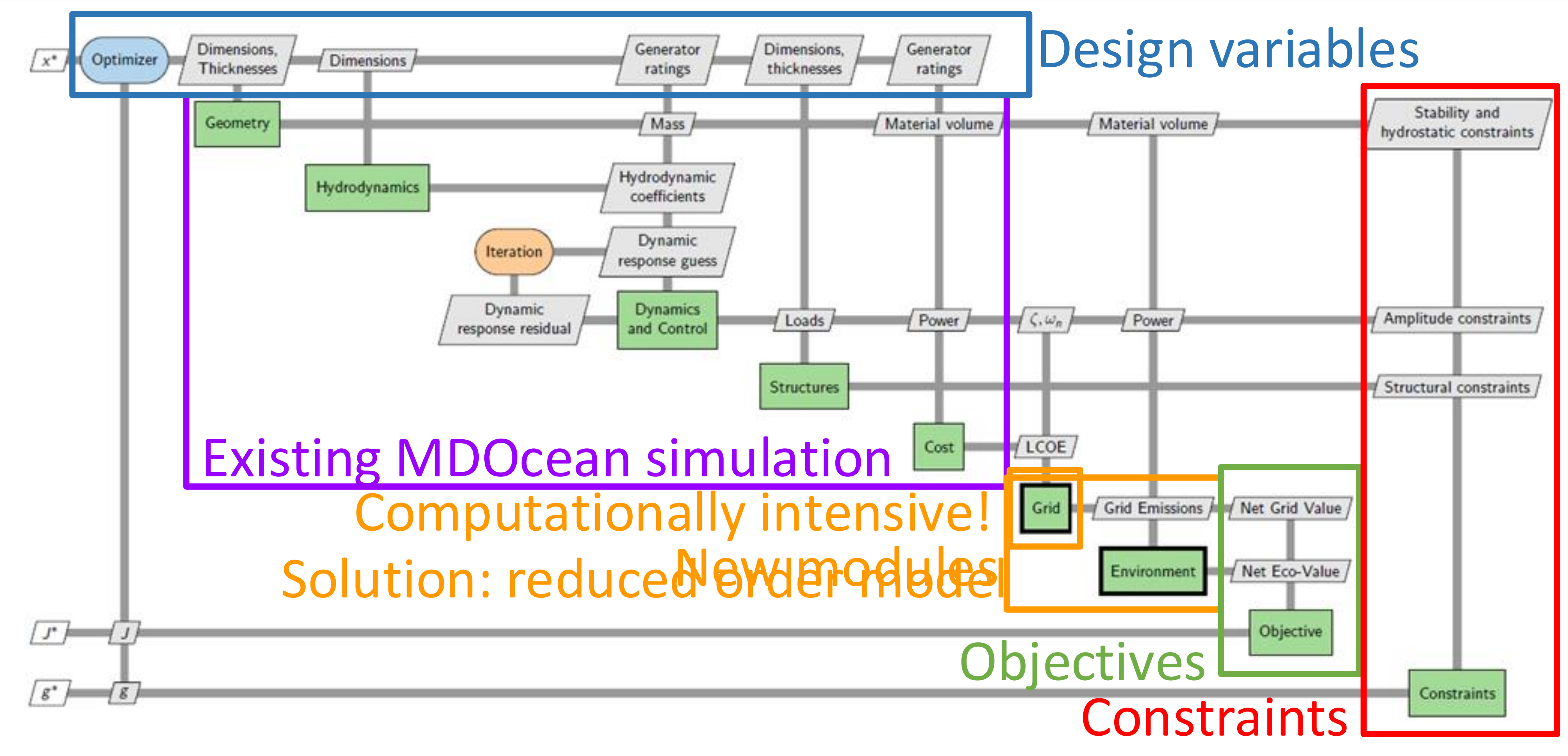
Better: NVOE
Project levelized viability
(if revenue offsets costs)



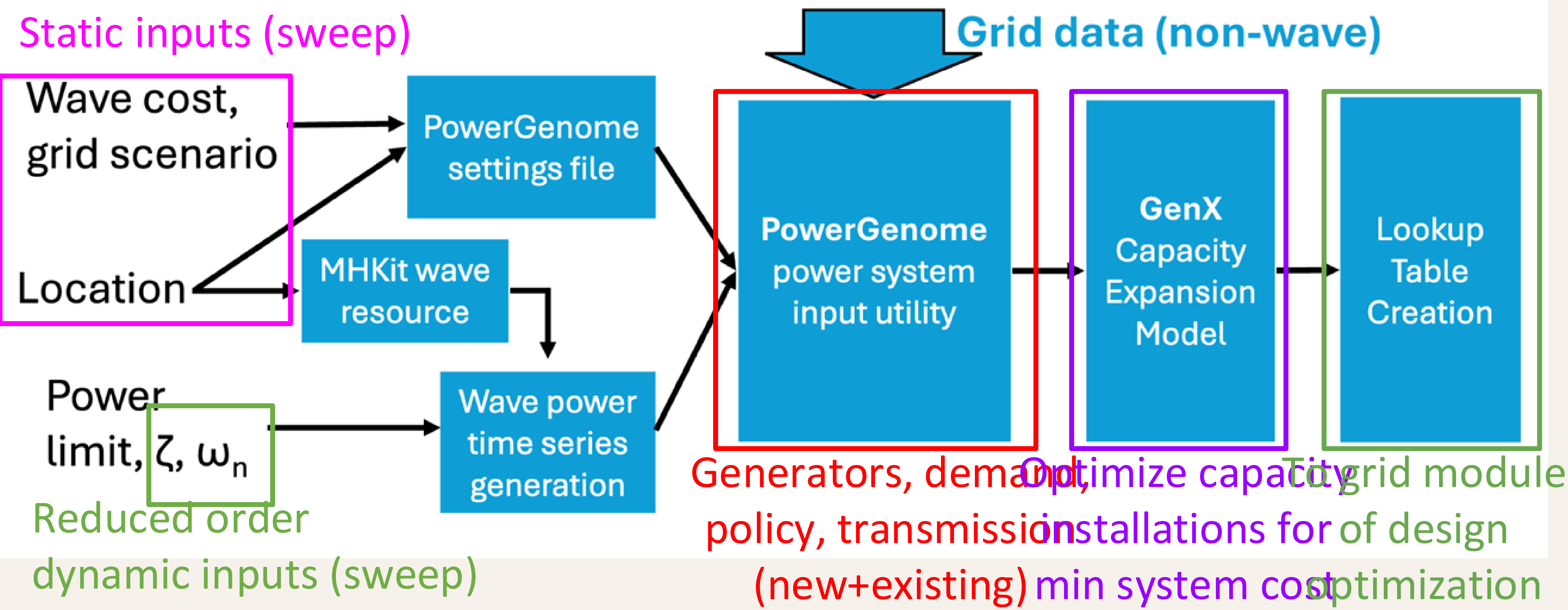
Best: Grid Cost
System levelized cost
(cost sum for all projects)



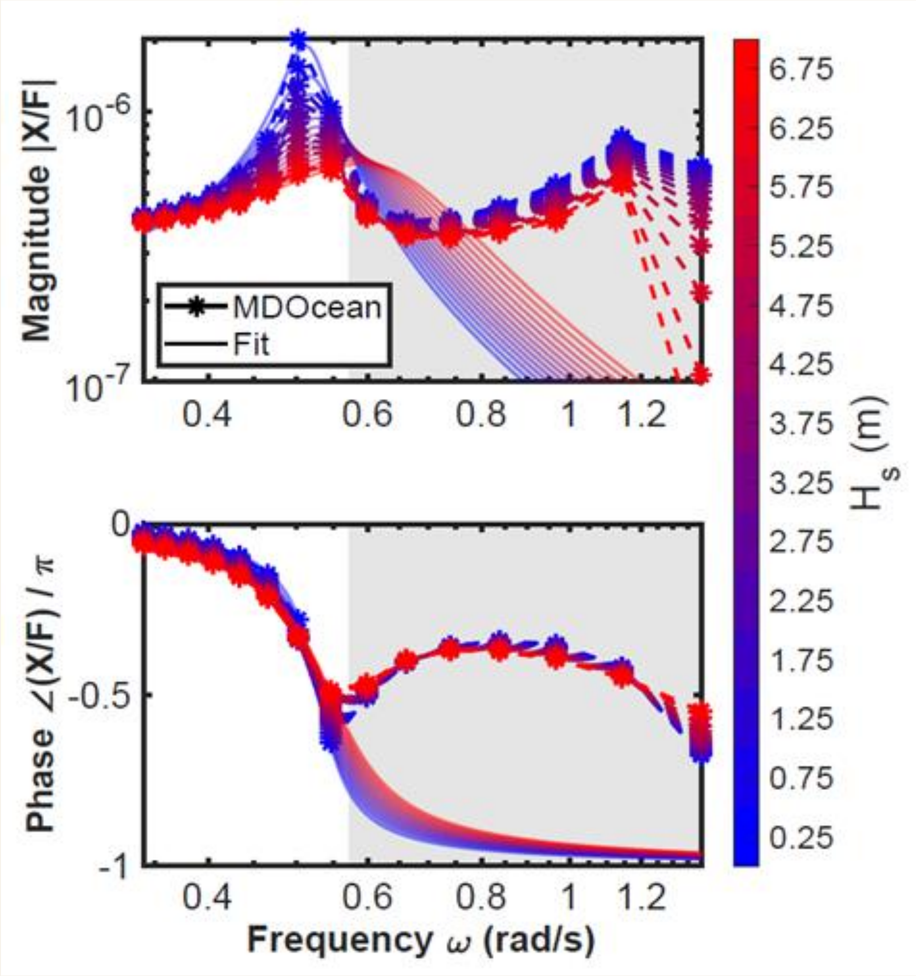
Methods: Optimization Structure

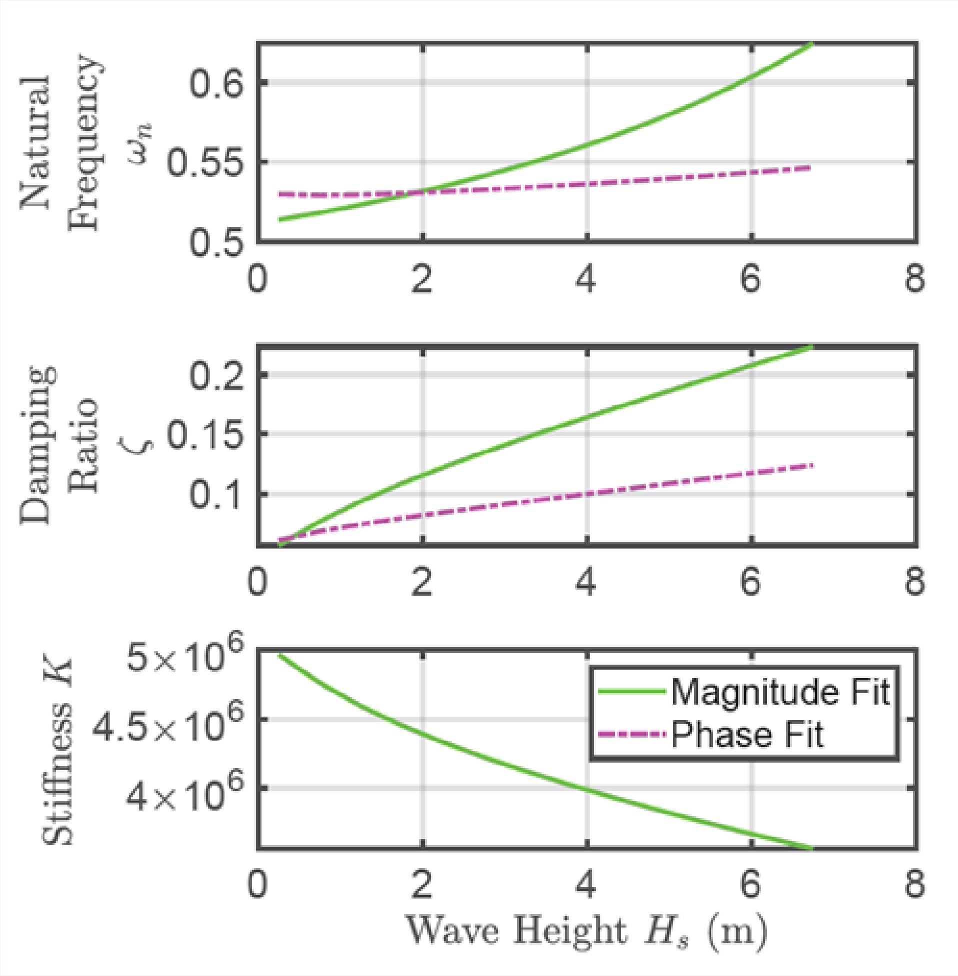


Methods: Grid Capacity Expansion Model



Methods: Reduced Order Model





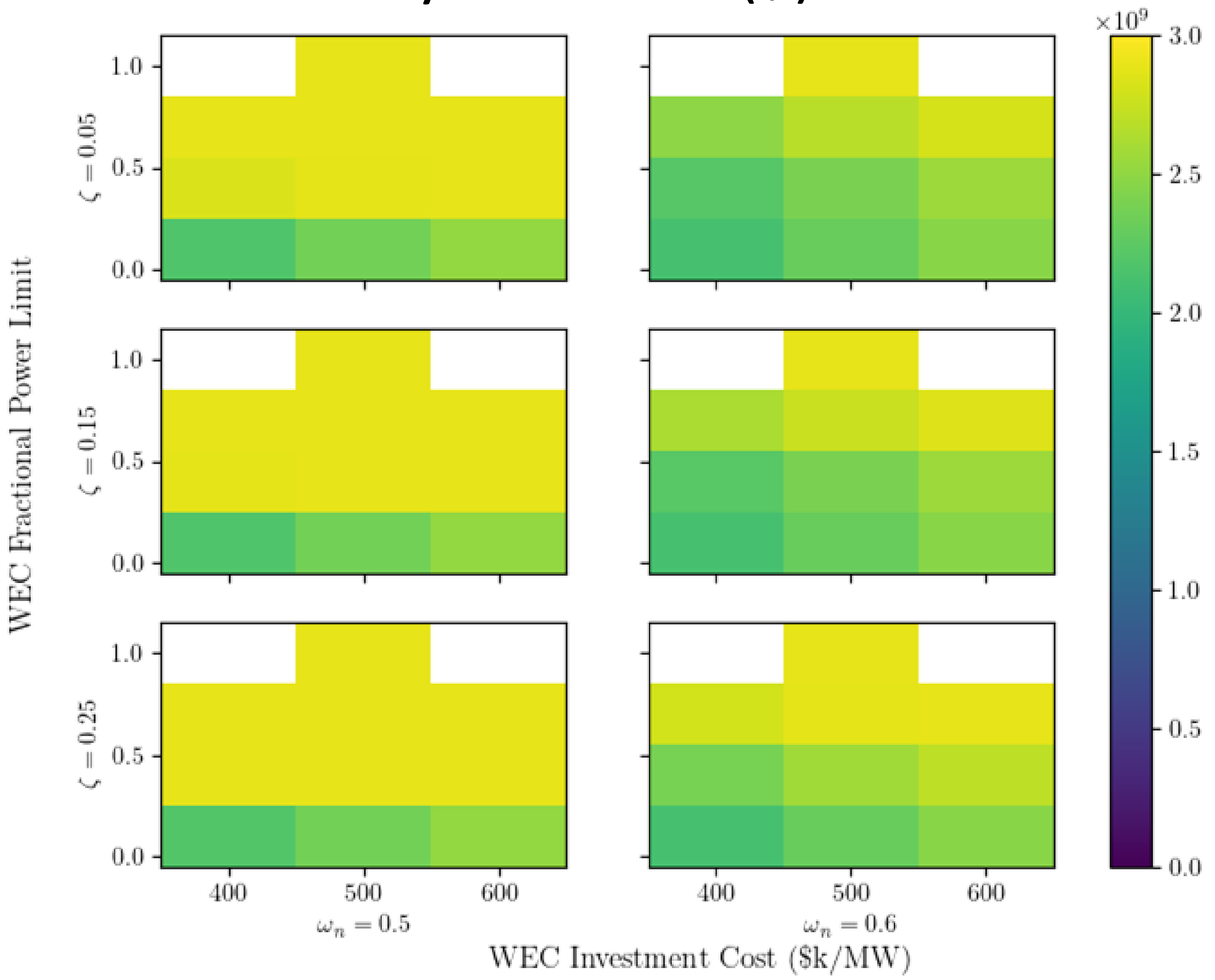
Methods: Environment Module

- **Net eco-value** compares levelized environmental benefits and harms
- Calculate **eco-cost** from material use and maintenance fuel emission
- Calculate **eco-value** from avoided grid emissions

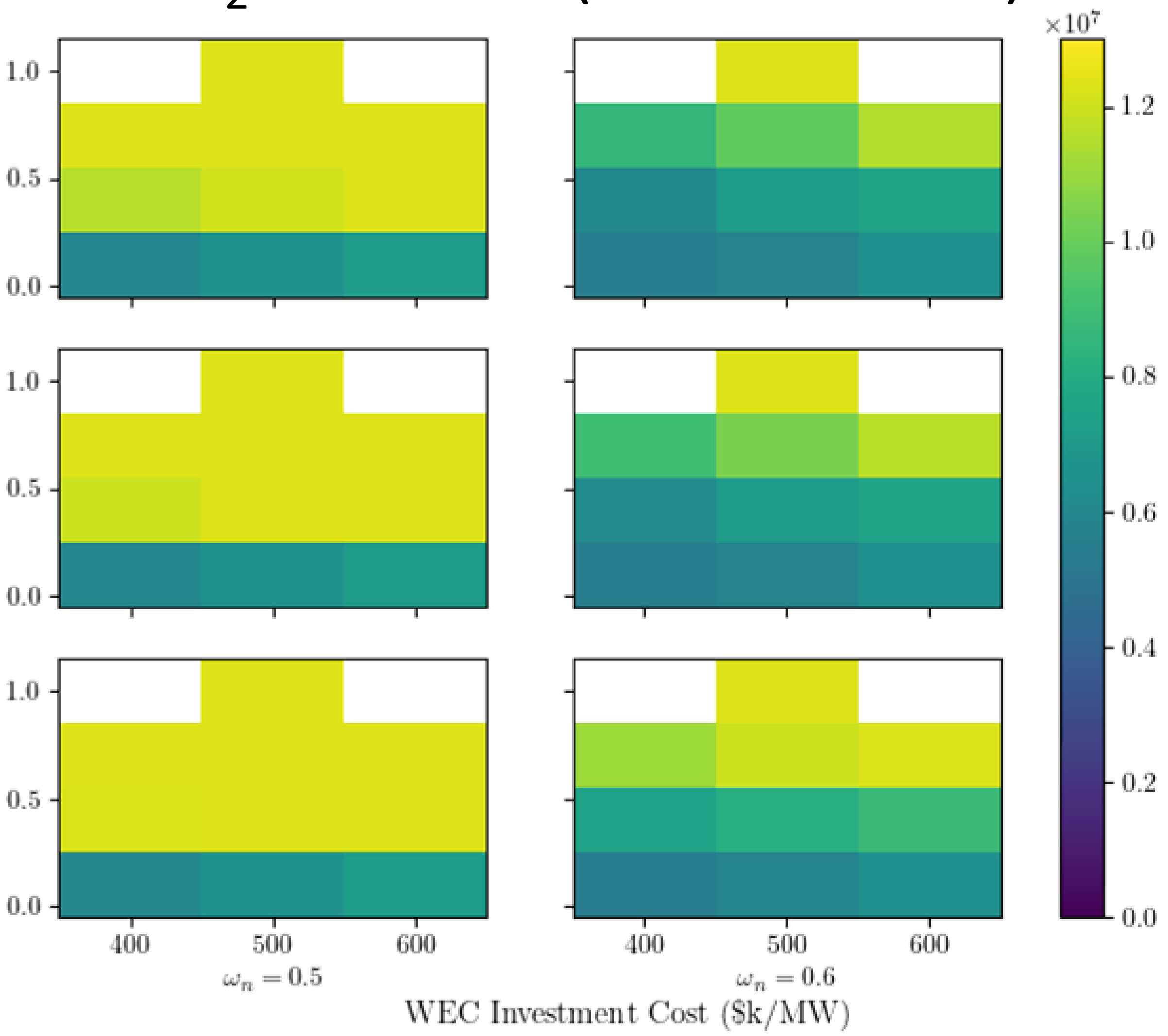
Component	Value
Steel	0.192 \$/kg
Fiberglass	6.950 $\$/m^2$
Distance from shore	65.88 \$/mile
Social cost of CO_2	0.145 $\$/kgCO_2$

Results: Capacity Expansion Model

System Cost ($)



CO_2 Emissions (metric tonnes)



Future Work

- Sweep remaining design parameters for comprehensive CEM results
- Investigate time-series results to understand where WEC value is derived
- Examine CEM sensitivity to date and location to avoid overfitting
- Obtain design optimization results over various grid scenarios to determine effect of optimizing for different metrics

Acknowledgements

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Connect

- Code is open-source and user-friendly!
- https://github.com/symbiotic-engineering/MDOcean optimization
- https://github.com/symbiotic-engineering/WEC-DECIDER capacity expansion

GitHub link

Paper link

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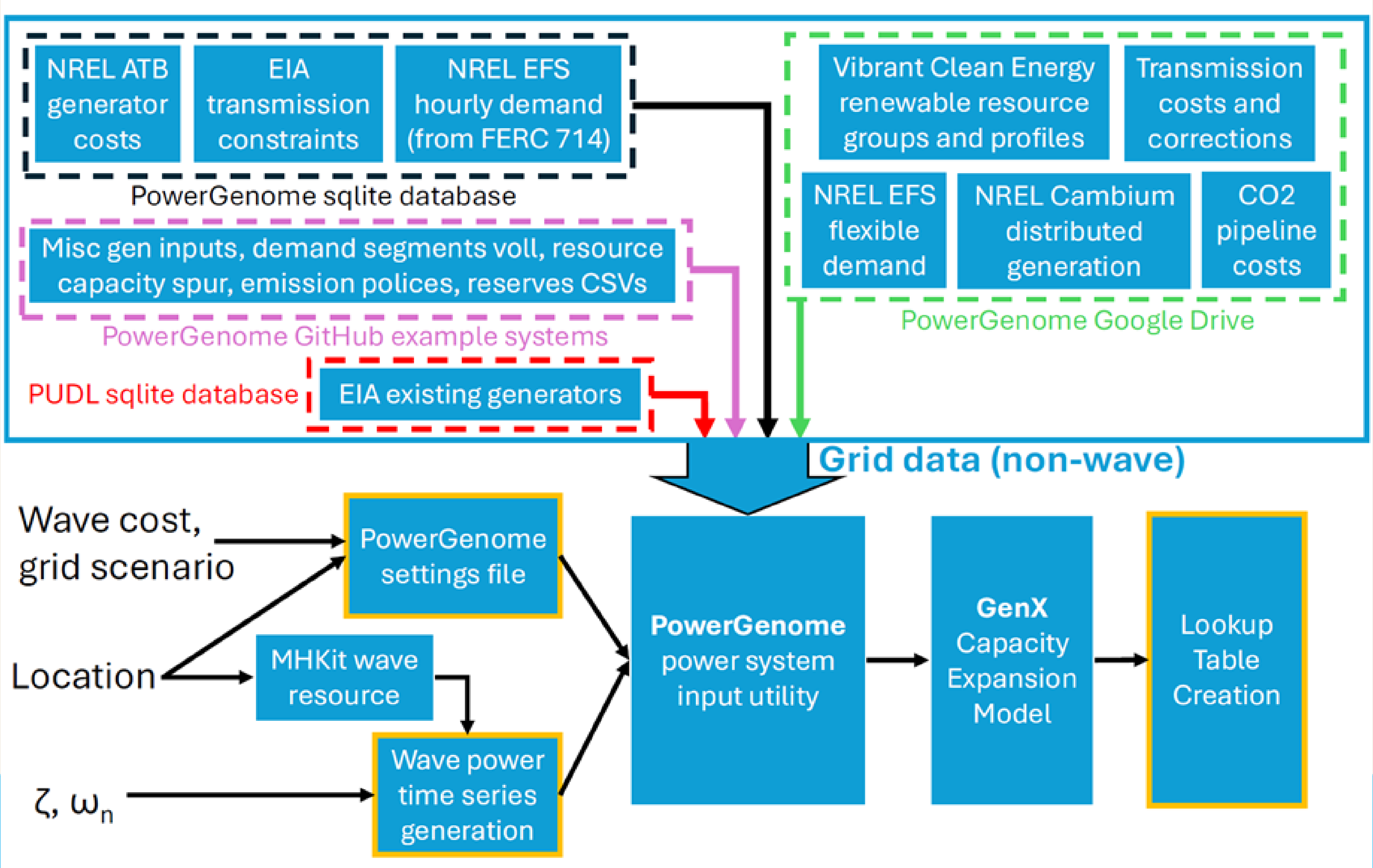
Appendix: PowerGenome Data Details



Appendix: Reduced Order Model Details

Symbol	Description
CW	Capture width
H_s	Significant wave height
T_e	Wave energy period
F_{lim}	Generator force limit
P_{lim}	Generator power limit
D_f	Float diameter
D_s	Spar diameter
T_f	Float draft
T_s	Spar draft
D_d	Damping plate diameter
t_d or h_d	Damping plate thickness
η_{PTO}	PTO efficiency
$C_{d,f}$	Float drag coefficient
$C_{d,s}$	Spar drag coefficient
C	Damping vs. reactive control type
h	Water depth
ρ	Water density
g	Gravitational acceleration
CW_{max}	Max radiative capture width $= Gg/\omega^2$
k	Wavenumber
ω	Wave angular frequency
F_{max}	Force at CW_{max}
P_{max}	Power at CW_{max}
Π_1	Set of 15 dimensionless groups
$\zeta_p, \omega_{n,p}$	Damping ratio and natural frequency of poles
$\zeta_z, \omega_{n,z}$	Damping ratio and natural frequency of zeros
τ_p, τ_z	Real pole/zero time constants
C_P, C_Z, R_P, R_Z	Number of complex/real poles and zeros
kD_f	Non-dimensional float diameter
B_0^e	Effective radiation damping coefficient
H_0	Hankel function (order zero)
N_0	Eigenfunction term
B_h	Hydrodynamic damping (Haskind relation)
$\mathcal{D}$	Depth function in B_h
A	Added mass (Kramers–Kronig relation)
$pv.$	Cauchy principal value

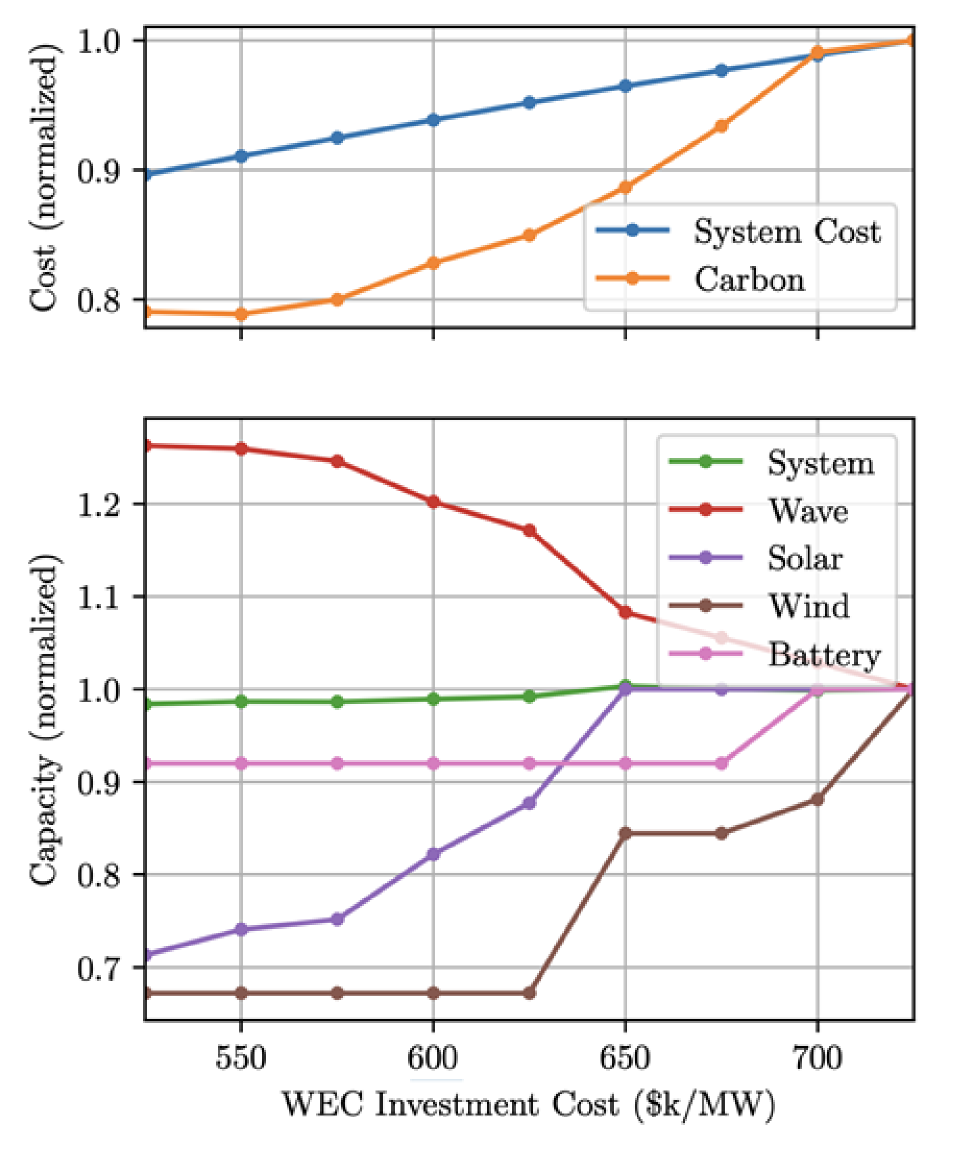
(1) $$\frac{CW}{CW_{max}} = \frac{4\mathcal{D}\eta_{PTO}}{G}\frac{\omega^2}{gk}\frac{\Re(\hat{Z}_h(\mathbf{\Pi_1}))\,\Re(\hat{Z}_u(\mathbf{\Pi_1}))}{\left|\hat{Z}_h(\mathbf{\Pi_1}) + \hat{Z}_u(\mathbf{\Pi_1}) + \hat{Z}_d(\mathbf{\Pi_1})\right|^2}$$

(2) $$\frac{CW}{CW_{max}} = f\left(\frac{H_s}{h}, kh, \frac{P_{lim}}{P_{max}}, \frac{F_{lim}}{F_{max}}, \frac{D_f}{h}, \frac{D_s}{D_f}, \frac{T_f}{T_s}, \frac{T_s}{h}, \frac{D_d}{D_f}, \frac{t_d}{D_d}, \eta_{PTO}, C_{d,f}, C_{d,s}, C\right)$$

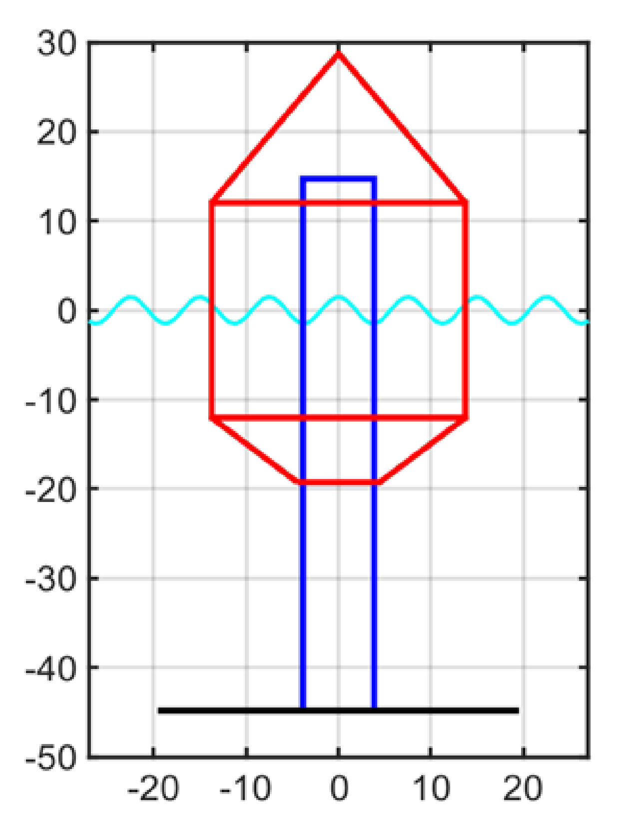
(3) $$\frac{\hat{X}}{\hat{F}} = \prod_{r_p=1}^{R_P}\prod_{r_z=1}^{R_Z}\prod_{c_p=1}^{C_P}\prod_{c_z=1}^{C_Z}\frac{1+\tau_{z,r_z}i\omega}{1+\tau_{p,r_p}i\omega}\times\frac{1-\left(\frac{\omega}{\omega_{n,c_z}}\right)^2 + i2\zeta_{c_z}\frac{\omega}{\omega_{n,c_z}}}{1-\left(\frac{\omega}{\omega_{n,c_p}}\right)^2 + i2\zeta_{c_p}\frac{\omega}{\omega_{n,c_p}}}$$

(4) $$\frac{\hat{F}}{\eta} = \frac{-4i\rho gh\sqrt{N_0}B_0^e}{\cosh(kh)\ H_0(kD_f/2)},\quad B_h = \frac{k\omega\ |\hat{F}/\eta|^2}{2\mathcal{D}\rho g^2},\quad A = \frac{1}{\pi\omega}pv.\int_0^\infty \frac{B(t)}{t-kD_f/2}dt$$

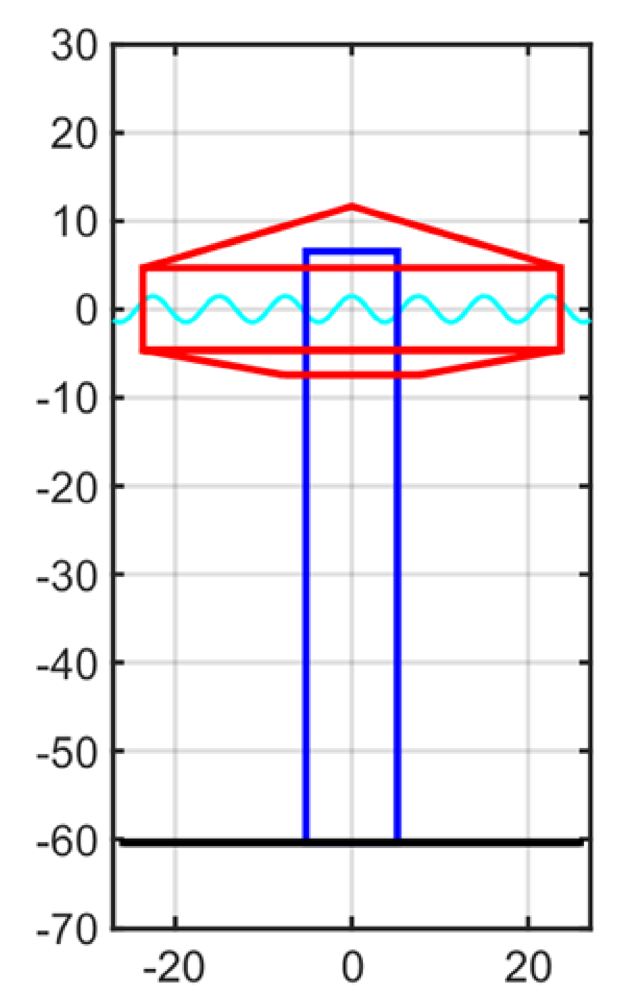
Appendix: CEM Cost Sweep for Nominal Variability



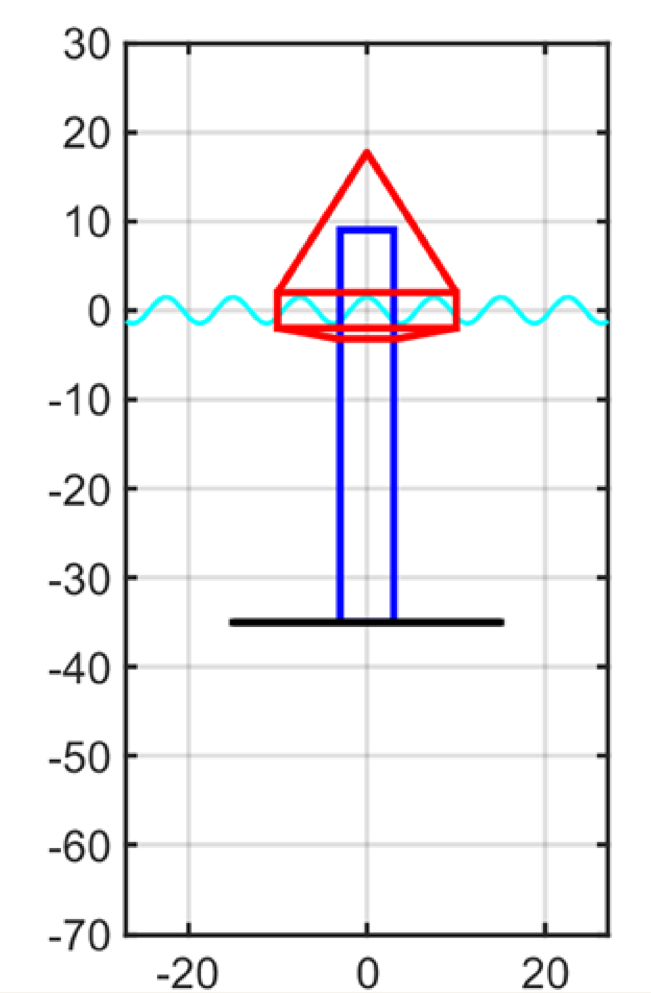
Appendix: Preliminary Design Optimization Results



Min grid cost



Min LCOE



Nominal RM3