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EWTEC 2019
Napoli, Italy

THE IMPORTANCE OF ENERGY STORAGE FOR WAVE POWERED MICROGRIDS

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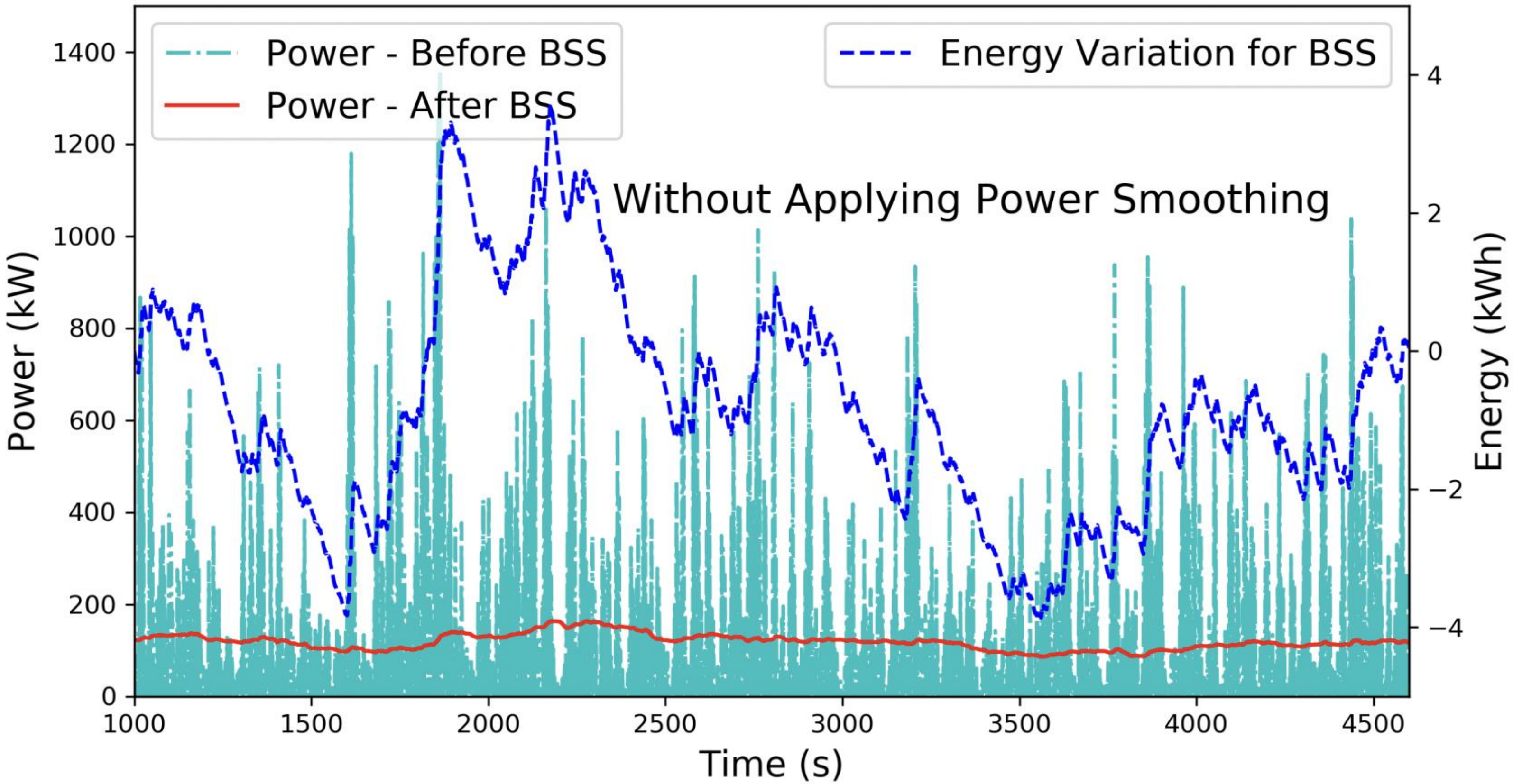
September 3, 2019

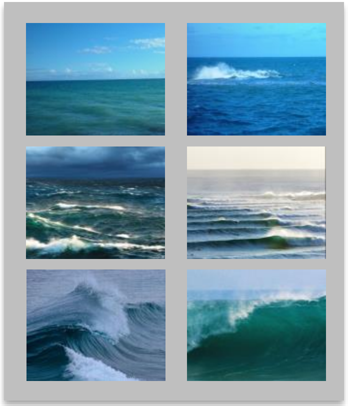
Motivation



Power - Before BSS
Power - After BSS
Energy Variation for BSS
Without Applying Power Smoothing
Power (kW)
Energy (kWh)
Time (s)
1400
1200
1000
800
600
400
200
0
4
2
0
−2
−4
1000
1500
2000
2500
3000
3500
4000
4500

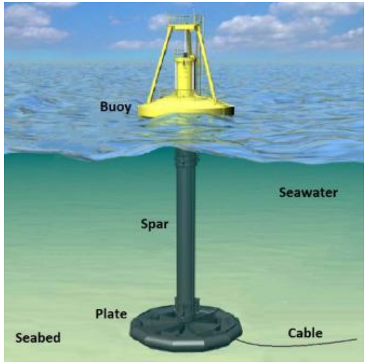
Methodology Overview

Wave Resource →



6 WEC Prize Sea States

Device Simulation →



WEC-Sim
With and without Power Smoothing

Battery Storage and Sizing →

Costs: 2018 EIA Battery Market Data

Grid Impact Analysis

PLEXOS Modeling

WEC-Sim Device Simulation

THE BASICS

WEC-Sim simulations

RM3 two-body **floating point absorber**

(6 Wave Energy Prize sea states)

Energy Storage

Estimate the required battery size and cost

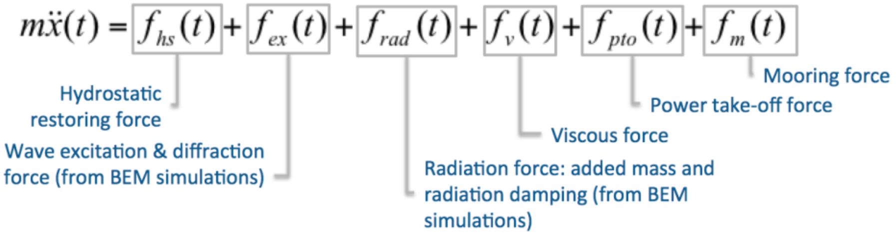
Grid Impact Analysis

Carried out using PLEXOS

Yu, Yi-Hsiang; Nathan Tom; Dale Jenne, 2018, "Numerical analysis on hydraulic power take-off for wave energy converter and power smoothing methods" Proceedings of the 37th international conference on Ocean, Offshore, and Arctic Engineering (OMAE) 2018, June 17-22, Madrid, Spain.

THE GORY DETAILS

- Dynamics simulated by solving time-domain equation of motion (Cummins, 1962)



$$m\ddot{x}(t) = \boxed{f_{hs}(t)} + \boxed{f_{ex}(t)} + \boxed{f_{rad}(t)} + \boxed{f_v(t)} + \boxed{f_{pto}(t)} + \boxed{f_m(t)}$$

- Use radiation and diffraction method and calculate the hydrodynamic forces from frequency-domain Boundary Element Method (WAMIT)

$$f_{rad}(t) = \underbrace{-A_\infty}_{\text{BEM}}\ddot{X} - \int_0^t \underbrace{K(t-\tau)}_{\text{BEM}}\dot{X}(\tau)d\tau$$

$$f_{ex}(t) = \Re\left[R_f \underbrace{F_X(\omega_r)}_{\text{BEM}} e^{i(\omega_r t+\phi)} \int_0^\infty \sqrt{2S(\omega_r)d\omega_r}\right] = \int_{-\infty}^{\infty} \eta(\tau) \underbrace{f_e(t-\tau)}_{\text{BEM}} d\tau$$

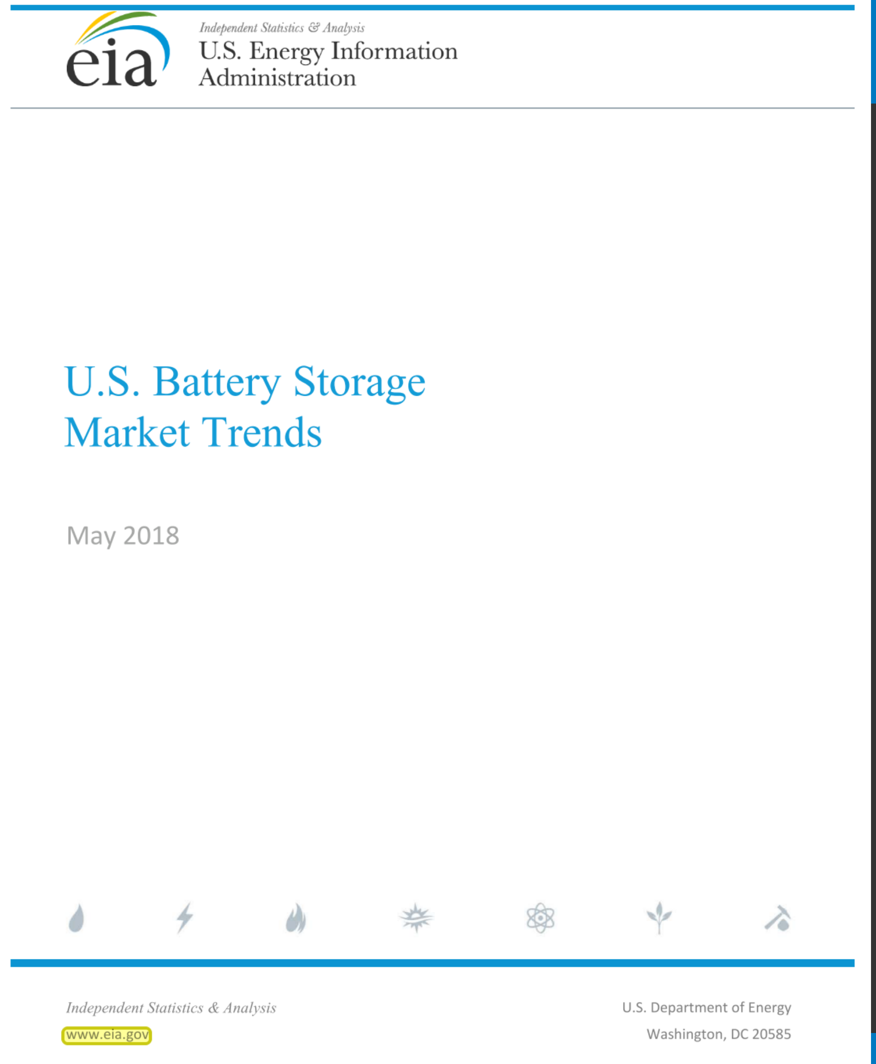
WEC-Sim Github page: https://github.com/WEC-Sim

Battery Size and Cost

- The power capacity or energy capacity were calculated based on the power output from the WEC-Sim simulation, assuming the power output from the battery was controlled based on the 10-minute-averaged input power.

$$\begin{aligned} \mathrm{E} &= \int_0^t (\mathrm{P} - \mathrm{P}_{\mathrm{10mins}})\, dt \\ \Delta\mathrm{E} &= \mathrm{Max(E)} - \mathrm{Min(E)} \end{aligned}$$

- We evaluated the battery storage needed and estimate its cost using the information from this EIA report.
- The cost of the battery was calculated for both power capacity and energy capacity scenarios for the WEC.



Independent Statistics & Analysis
U.S. Energy Information
Administration

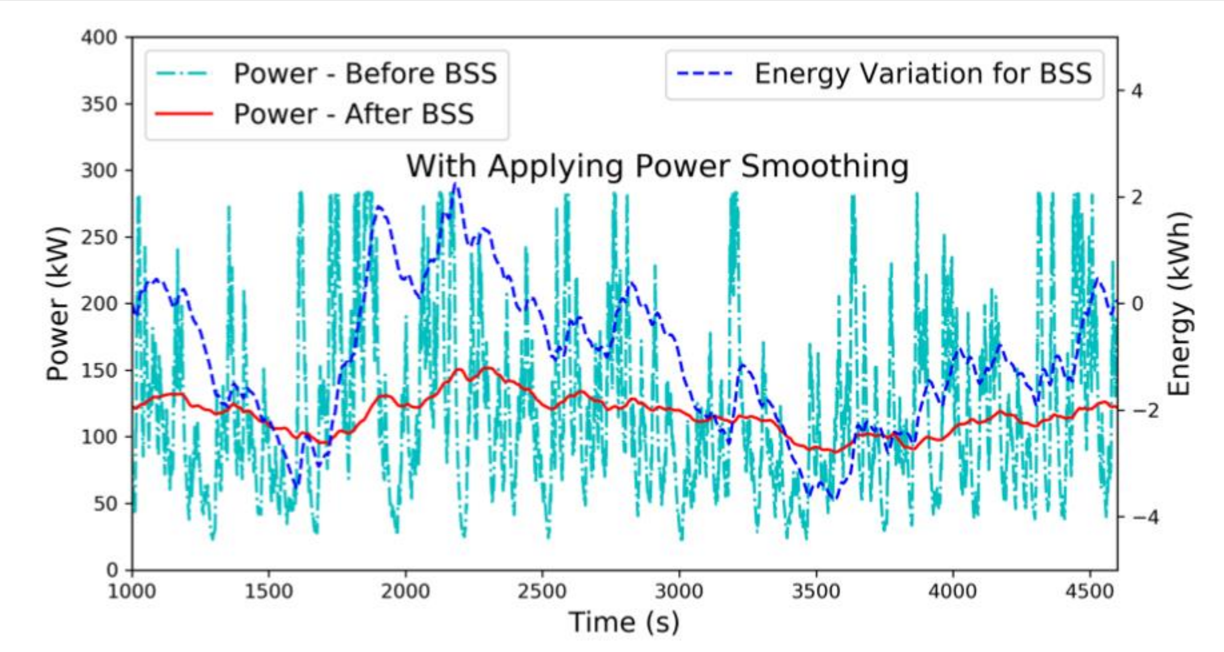
U.S. Battery Storage
Market Trends

May 2018

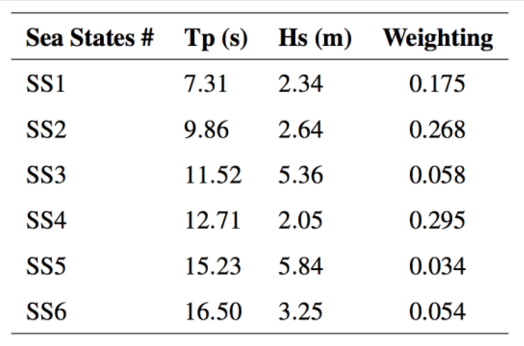
Independent Statistics & Analysis
www.eia.gov

U.S. Department of Energy
Washington, DC 20585

Battery Size and Cost



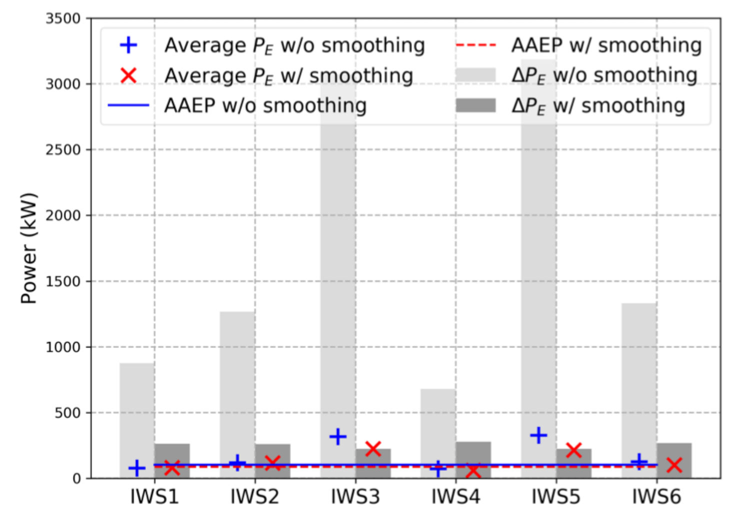
An example of the the time history for the power output and energy variation from the WEC-Sim simulation, which can be useful for analyzing the energy storage and grid system.

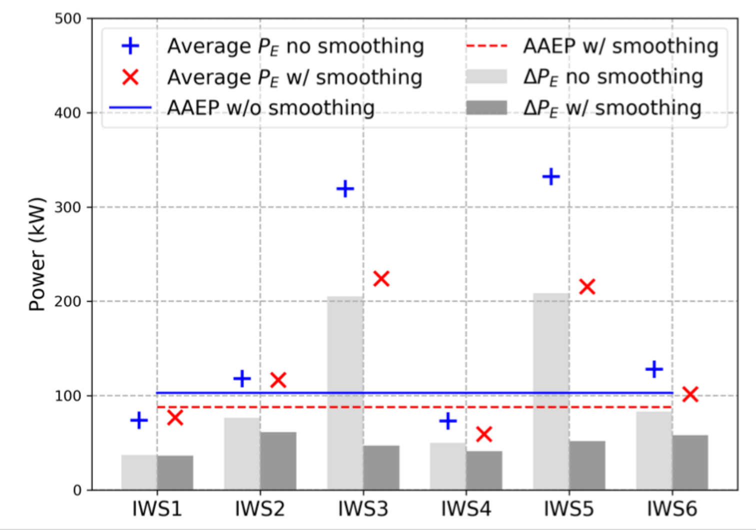


Sea States #	Tp (s)	Hs (m)	Weighting
SS1	7.31	2.34	0.175
SS2	9.86	2.64	0.268
SS3	11.52	5.36	0.058
SS4	12.71	2.05	0.295
SS5	15.23	5.84	0.034
SS6	16.50	3.25	0.054

- Six Wave Energy Prize sea states were used in WEC-Sim simulations.
- Adjusted weighting function is given based on the wave environment for Newport, Oregon (Bull et al., OMAE2017).

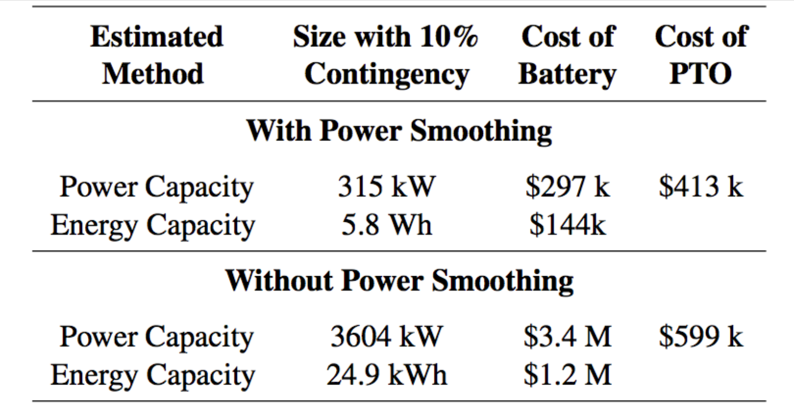
Battery Size and Cost



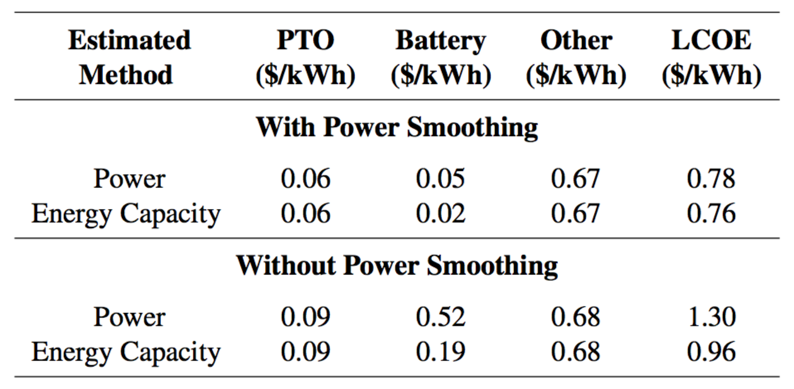


- The figures on the left shows the overall power quality before charging to the battery.
- The figures on the right shows the overall power quality after discharging from the battery.
- Assuming no energy losses for battery storage

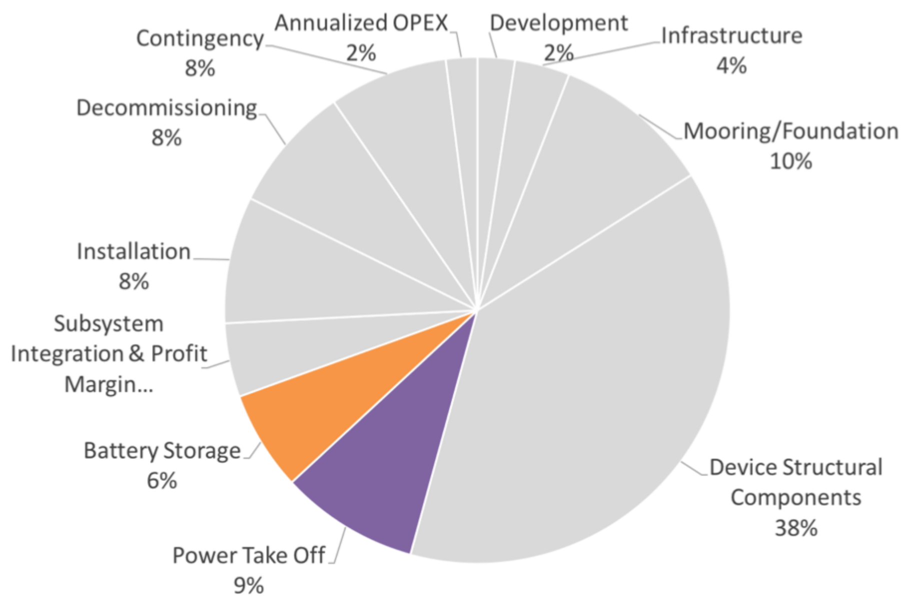
Battery Size and Cost



Estimated Method	Size with 10% Contingency	Cost of Battery	Cost of PTO
With Power Smoothing			
Power Capacity	315 kW	$297 k	$413 k
Energy Capacity	5.8 Wh	$144k	
Without Power Smoothing			
Power Capacity	3604 kW	$3.4 M	$599 k
Energy Capacity	24.9 kWh	$1.2 M	



Estimated Method	PTO ($/kWh)	Battery ($/kWh)	Other ($/kWh)	LCOE ($/kWh)
With Power Smoothing				
Power	0.06	0.05	0.67	0.78
Energy Capacity	0.06	0.02	0.67	0.76
Without Power Smoothing				
Power	0.09	0.52	0.68	1.30
Energy Capacity	0.09	0.19	0.68	0.96



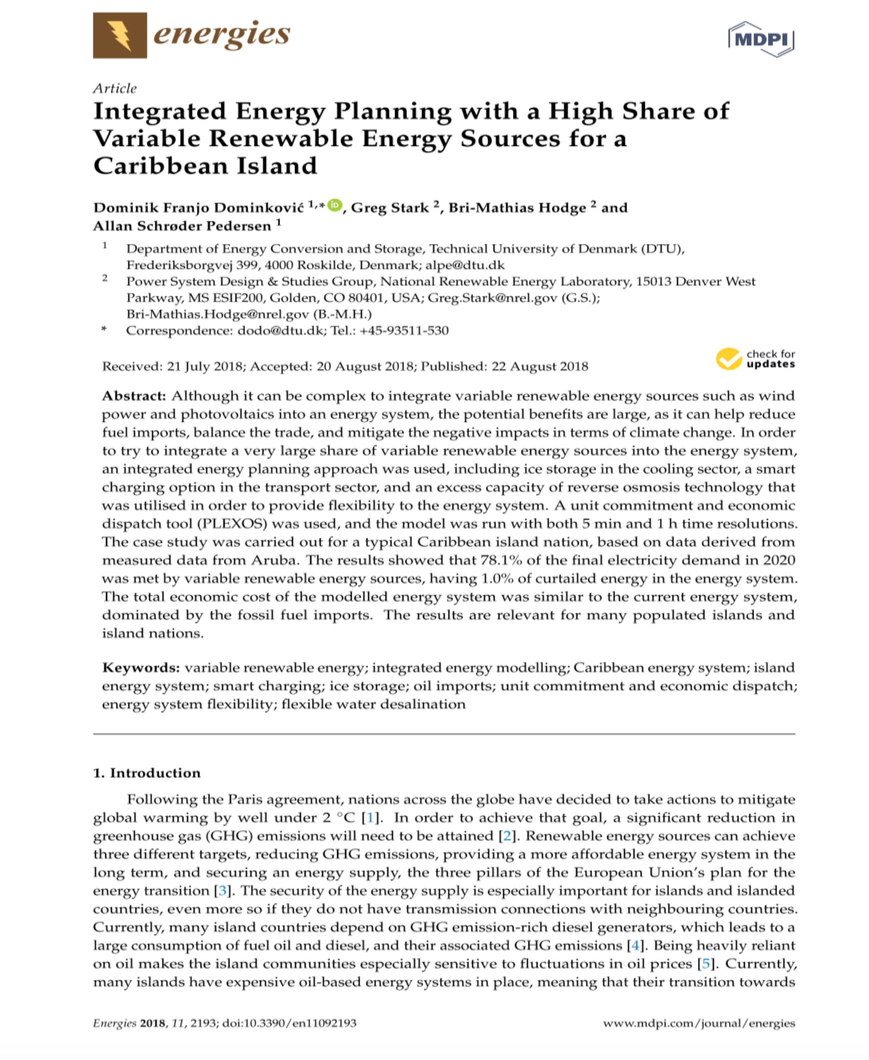
PLEXOS simulation

- The load used was a down-scaled version of actual 2012 data for an island.

- A small island system with a peak of 5 MW and three diesel generators.

- The case study also includes
  - Heat rate changes that affect the generator efficiency,
  - Start costs and minimum downtime, and start time for the diesel generator.

- This is a highly simplified version of a grid that allows for some insight into how WEC-generated power could contribute to a small island electricity system.



energies

MDPI

Article

Integrated Energy Planning with a High Share of Variable Renewable Energy Sources for a Caribbean Island

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Abstract: Although it can be complex to integrate variable renewable energy sources such as wind power and photovoltaics into an energy system, the potential benefits are large, as it can help reduce fuel imports, balance the trade, and mitigate the negative impacts in terms of climate change. In order to try to integrate a very large share of variable renewable energy sources into the energy system, an integrated energy planning approach was used, including ice storage in the cooling sector, a smart charging option in the transport sector, and an excess capacity of reverse osmosis technology that was utilised in order to provide flexibility to the energy system. A unit commitment and economic dispatch tool (PLEXOS) was used, and the model was run with both 5 min and 1 h time resolutions. The case study was carried out for a typical Caribbean island nation, based on data derived from measured data from Aruba. The results showed that 78.1% of the final electricity demand in 2020 was met by variable renewable energy sources, having 1.0% of curtailed energy in the energy system. The total economic cost of the modelled energy system was similar to the current energy system, dominated by the fossil fuel imports. The results are relevant for many populated islands and island nations.

Keywords: variable renewable energy; integrated energy modelling; Caribbean energy system; island energy system; smart charging; ice storage; oil imports; unit commitment and economic dispatch; energy system flexibility; flexible water desalination

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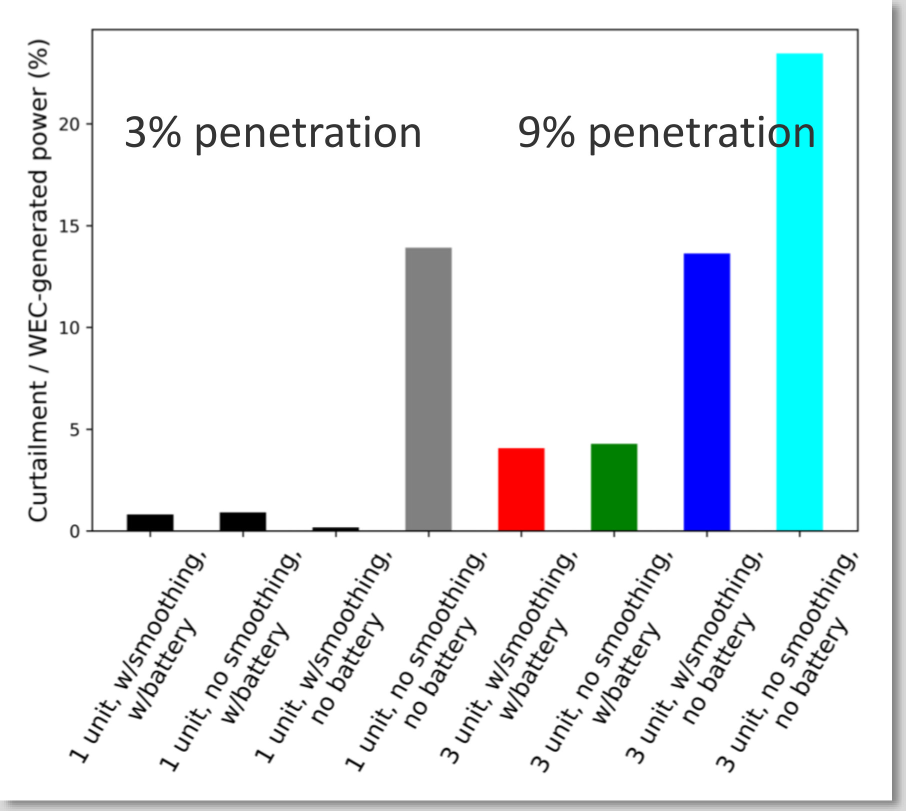
1. Introduction

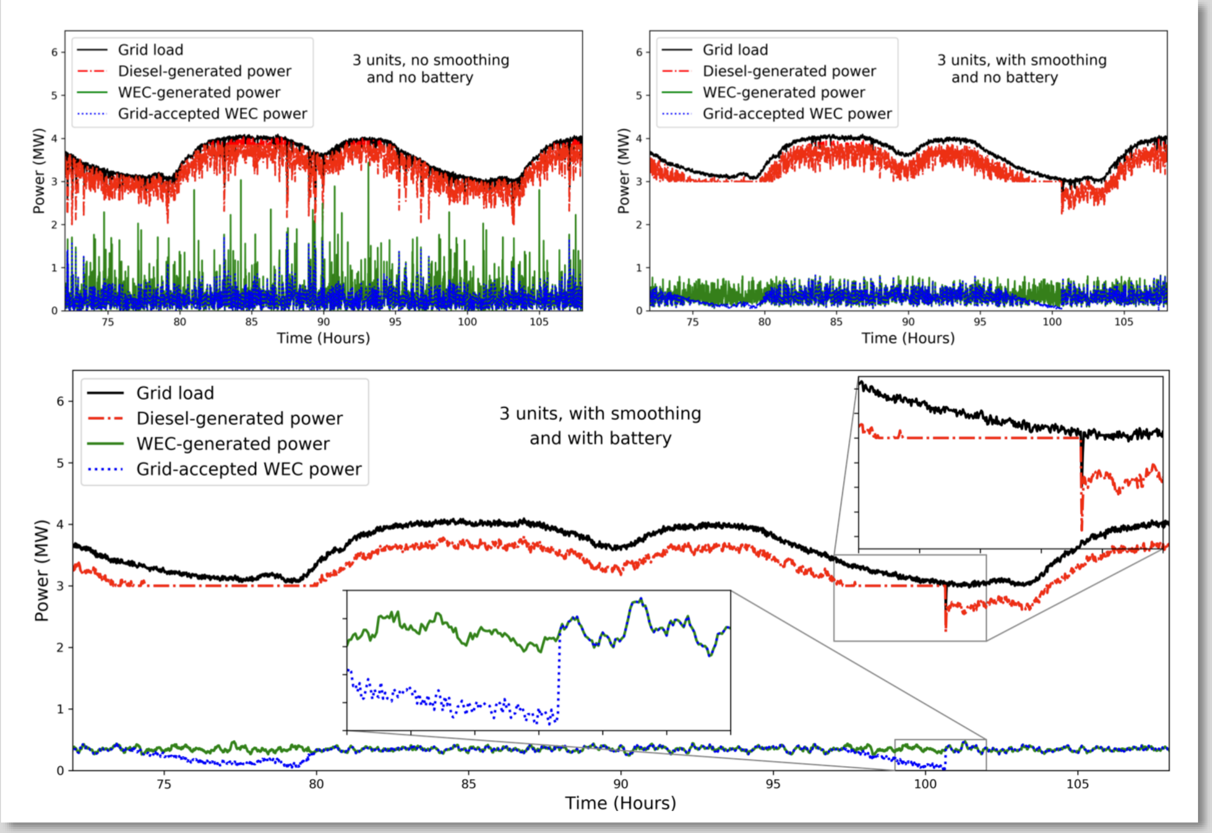
Following the Paris agreement, nations across the globe have decided to take actions to mitigate global warming by well under 2 °C [1]. In order to achieve that goal, a significant reduction in greenhouse gas (GHG) emissions will need to be attained [2]. Renewable energy sources can achieve three different targets, reducing GHG emissions, providing a more affordable energy system in the long term, and securing an energy supply, the three pillars of the European Union's plan for the energy transition [3]. The security of the energy supply is especially important for islands and islanded countries, even more so if they do not have transmission connections with neighbouring countries. Currently, many island countries depend on GHG emission-rich diesel generators, which leads to a large consumption of fuel oil and diesel, and their associated GHG emissions [4]. Being heavily reliant on oil makes the island communities especially sensitive to fluctuations in oil prices [5]. Currently, many islands have expensive oil-based energy systems in place, meaning that their transition towards

PLEXOS simulation



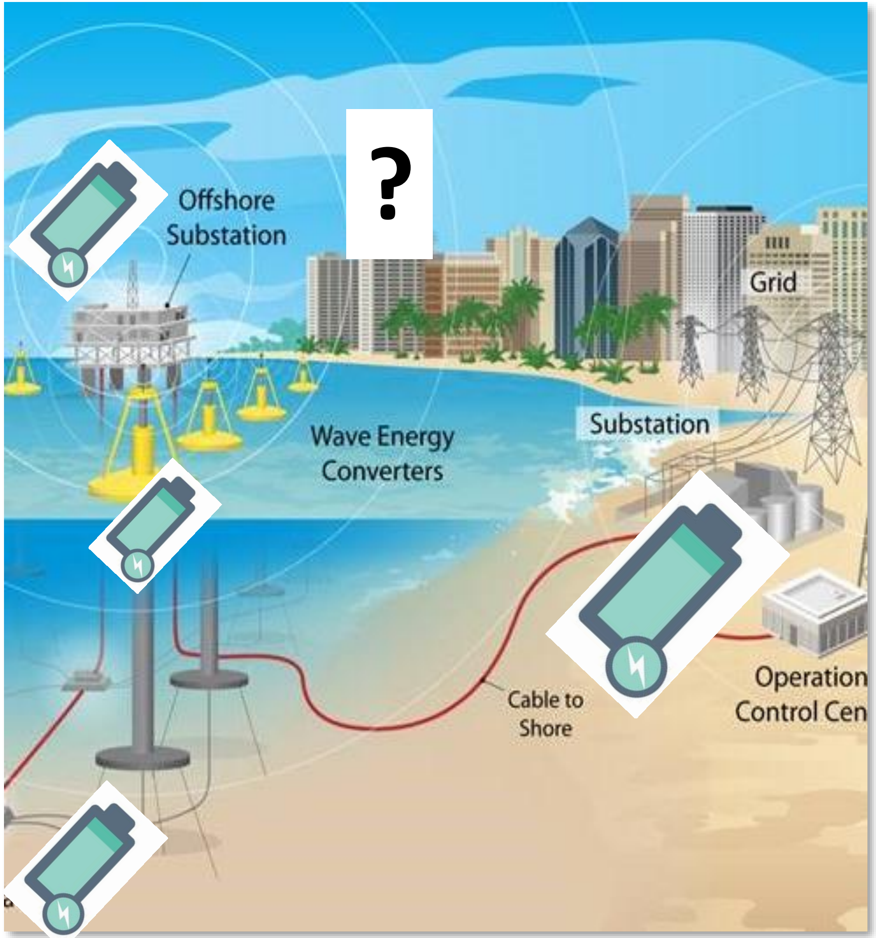
- Sampled each minute for a day based on the simulation results from WEC-Sim for a design-operational wave condition
- Violation of the diesel generator flexibility constraints -> Curtailment of the wave generation
- Three units were created from each single-WEC unit case (with 4 s offset).
- Little curtailment needed in 3% penetration cases

PLEXOS simulation



Summary

- Evaluated the potential battery storage size and cost for WEC (driven by the peak power)
- Performed a preliminary grid integration analysis using PLEXOS
- Required some kind of energy storage and power smoothing
- Future work includes
  - Cost estimation of undersea cables and subsea stations, control strategies, and the potential and cost of using other energy storage technologies.
  - Detailed analysis on the impact to the grid system and larger wave energy penetration cases



Thank You!

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